GROUNDWATER POLLUTION FROM LANDFILL SITE ON PERVIOUS SANDY SOIL - A Case Study of Pollution Control

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Introduction

Landfilling is the most commonly used method of disposal for minicipal wastes. This method is generally the simplest, most flexible, reliable and most economical means of disposing these wastes. One major problem with landfilling however is that it generates leachate.

In Perth, where landfills are generally situated on sandy soils, leachate movement through the underlying soils to ground water is relatively a rapid process. The attenuation of organic materials by the soil is very limited. Reduction of COD by methane fermentation in the field situation may potentially take place when the leachate has entered groundwater and begun to flow horizontally.

Field studies were carried out at the City of Bayswater completed landfill site and divided into two sections. The first section was leachate monitoring designed to establish the characteristic of leachate, i.e. its flow and quality patterns over time. In the second section of the studies, leachate was used for irrigating grasses. The main aim of the second studies was to examine the potential use of leachate irrigation as a means of pollution control of groundwater and at the same time providing a source of nutrients for plants.

2. History of The Site

The study area is located approximately six kilometers North-East of the Perth City Centre, east of Garratt Road bridge and between Guilford Road and the Swan River. The landfill covers an area of 36.7 hectares. The site was originally a flood plain area and the conversion into the landfill took place in 1956. It was filled up for 25 years with municipal waste including domestic commercial, building and industrial solid wastes (Smith, 1985). A clay bund was constructed around the site before the filling operation started for the retention of leachate.

The area is divided into two sections by a storm drain carrying water from an industrial area North of the site. The Western side of the drain was filled up with rubbish from 1956 to 1971 and the Eastern side was filled up from 1972 to 1981. The thickness of the fill varies from about 1m at the northern boundary to 8.5 m near the centre of the eastern sector. The solid waste was compacted to an average density of about 350 kg/m^3. During the filling operation a lake was created in the middle of the area (immediately east of the storm-drain.

3. Site Characteristics

Site investigation was carried out with the aim of finding appropriate locations for siting monitoring bores. Information about the study area and the surrounding area was collected. Bore log data were obtained from the Geological Survey record (bore 401 and bore 719). Information on potentiometric contours of the area were obtained from the Water Board. This information was analysed and summerised in the form of a map as depicted in Figure 1.

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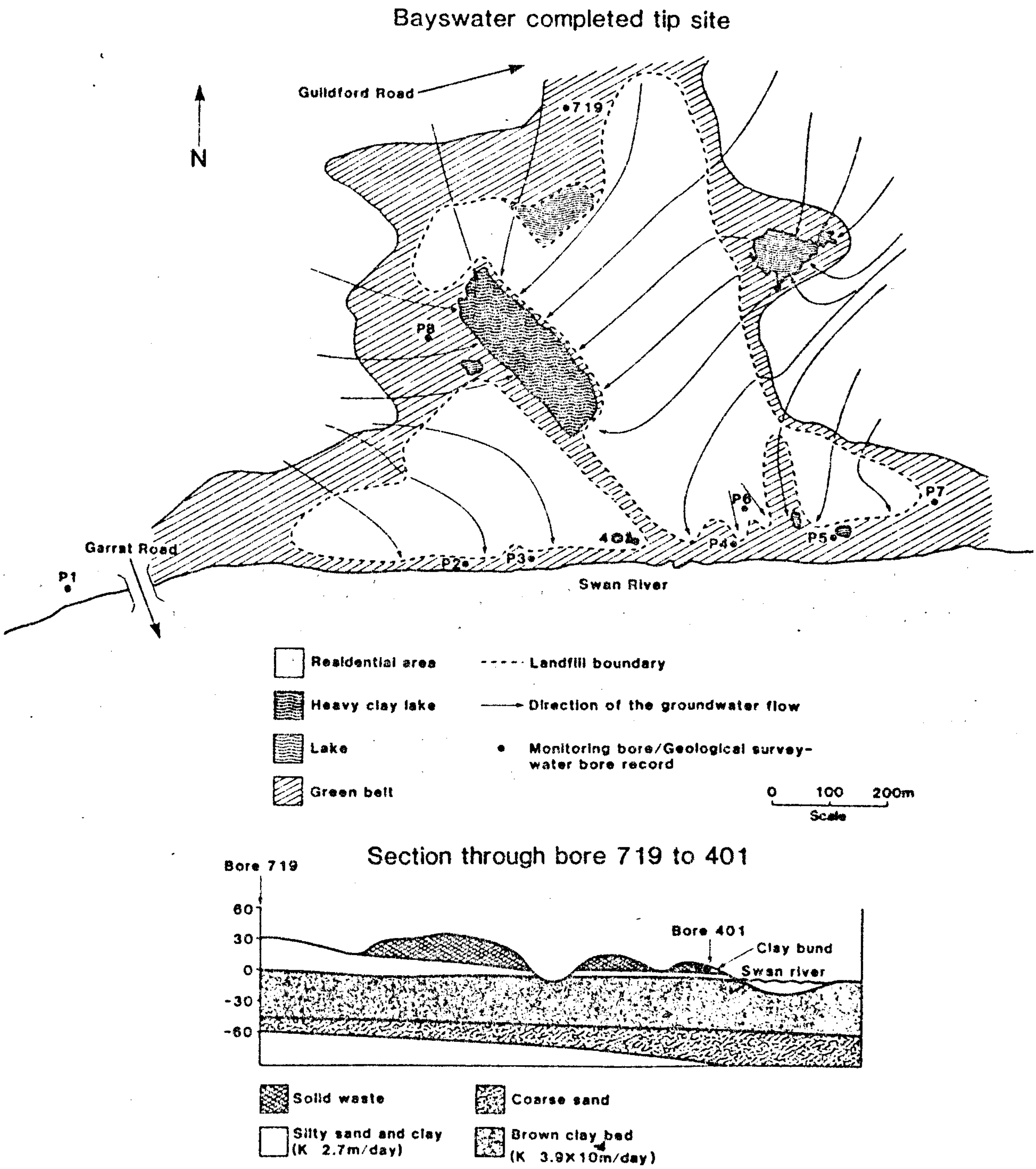


FIGURE 1. SITE CHARACTERISTIC OF THE BAYSWATER COMPLETED LANDFILL AND THE GEOLOGICAL CROSS-SECTION OF THE LANDFILL

A geological cross-section of the area was drawn based on the bore log data of the Geological Survey, Western Australia. Further information about soil strata of the area was found during the installation of monitoring bores. A few details about the site were not possible to be included in the cross-section, including the presence of a peat layer above the silty sand layer at varying thickness ranging from several centimeters to about 0.5 m. This peat layer is especially common in the area between the landfill and the Swan River

From the cross-section it can be seen that the landfill is underlain by sand layer. This sand layer becomes thinner toward the river. As revealed during the construction of monitoring bores (between the landfill and the river) the thickness of the sand layer varies from 0 (missing) to about 1m. Monitoring bore P5 has a layer of clean sand with a perched water table higher than the surrounding area.

Underneath the silty sand layer is a thick heavy clay layer. The thickness is about 12.6 m at bore 401. Samples of the sand and clay soils were taken for determination of saturated hydraulic conductivity. The conductivity value (K) was found to be 2.7 m/day for the sand and 3.9^{-4}m/day for the clay.

4. Groundwater Quality Monitoring

Eight monitoring bores (i.d=105 mm) were sunk to the underlying clay layer. Five of the bores were located between the landfill and the Swan River and the other three were located far from the landfill as control bores. The location of these bores are indicated in Figure 1 as P1, P2, P3, P4, P5, P6, P7 and P8. Each bore was provided with a slotted PVC casing at the lower part, non-slotted PVC casing at the upper part and an air tight lid.

The monitoring bores were sited to intercept possible leachate flow from the landfill to the river. Therefore consideration was given to ground water flow direction and soil strata. It was decided that a deep monitoring bore penetrating the thick clay layer was not necessary because the leachate could only flow through the sand layer above the clay layer. However this sand layer is missing or become very thin in some places between the landfill and the river.

The monitoring programme comprised two periods. Each period lasted for about five months. During the first period, water samples were collected every month (normally in the third week) from June to October. This represented a wet period which included a period of high water table. The second period was carried out during a dry period representing a period of low water table (Figure 2).

Before taking water samples, the water inside the bore was bailed out to removed approximately the volume of water retained in the bore. This procedure was carried out in order to get a fresh water sample from the ground without prolong contact with the air inside the bore. Samples of water were also taken from the main lake. Water samples from bore P2 and P3 (older site) were yellowish in colour and upon prolonged contact with the air formed a brown precipitate of iron oxide. Samples from the other bores were clear.

All the samples were analysed for their pH, electrical conductivity, total dissolved solids, Cl, ammonia-N, ortho-P and COD. BOD was also analysed but only occasionally. These parameters were chosen firstly because they are normally in leachate at high concentration and secondly to evaluate the suitability of the water for irrigation.

5. Results and Discussion

Results of the analyses of COD, ortho-P and ammonia-N are presented in Figure 3, Figure 4 and Figure 5 respectively. Ammonia-N and COD were found to indicate leachate movement more than the other parameters.

Results of the analyses of pH, Chloride and Total Dissolved Solids (TDS) are presented in Table 1.

Area and Season		pH	TDS mg/L	Cl mg/L	Conductivity mS/cm
Area 1 season 1:					
	Range	6.2-7.2	8500-25000	2330-10200	9.9-25.5
	Average	6.7	13800	5750	
Area 1 season 2:					
	Range	6.4-7.7	2800-24600	-	3.2-28.5
	Average	6.9	12700	-	14.2
Area 2 season 1:					
	Range	6.8-7.1	2200-8750	410-5350	2.8-3.6
	Average	7.0	3120		3.3
Area 2 season 2:					
	Range	7.1-8.1	600-2200	-	1.3-1.7
	Average	7.4	1240	-	1.5
Lake season 1:					
	Range	8.1-9.2	1000-2000	331-800	2.1-2.6
	Average	8.5	1550	530	2.3
Lake season 2:					
	Range	8.1-9.4	1100-4400	-	1.7-4.6
	Average	8.8	2710	-	3.3
Control season 1:					
	Range	6.2-6.8	4600-32800	2180-14350	7.3-41.8
	Average	6.5	13900	8750	30.0
Control season 2:					
	Range	6.2-7.8	8000-223320	-	15.3-24.8
	Average	7.1	12550		19.5

TABLE 1. RANGE AND AVERAGE VALUE OF pH, TOTAL DISSOLVED SOLIDS CHLORIDE AND CONDUCTIVITY. AREA 1 FROM BORE p2 AND P3, AREA 2 FROM BORE P4 and P6 AND CONTROL FROM BORE P1 AND P7.

Chloride, electrical conductivity and TDS are commonly good indicators for leachate pollution. However in this study they could not be used as indicators because the influence of saline river water was very strong.

Many parts of the area near the river were flooded by the saline water (up to about 30%) from the river in winter. This is the reason for the high salt content (TDS). As the water level in the river receded after winter, displacement by groundwater took place. Consequently lower levels of salt content in water samples were found. However the levels were still higher than normally found in leachate.

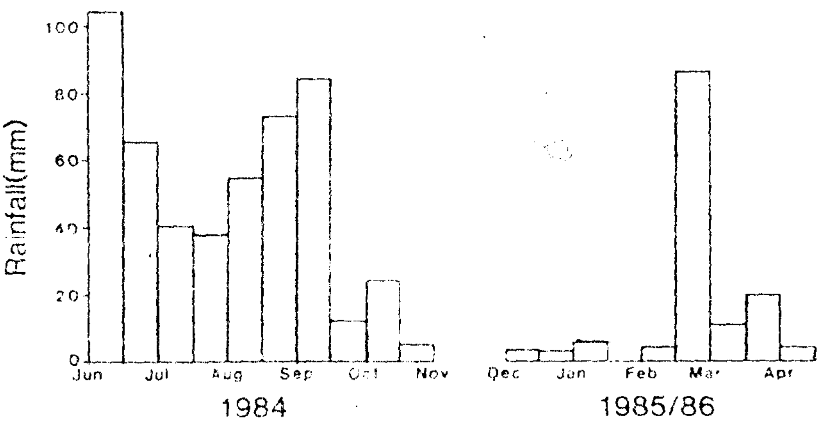
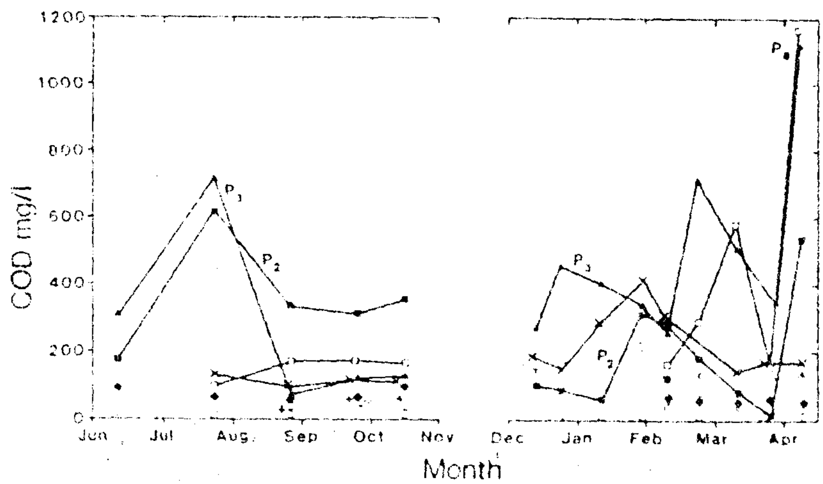


FIGURE 2. RAINFALL DISTRIBUTION DURING THE FIELD MONITORING AND IRRIGATION PERIODS

FIGURE 3. COD IN WATER SAMPLES



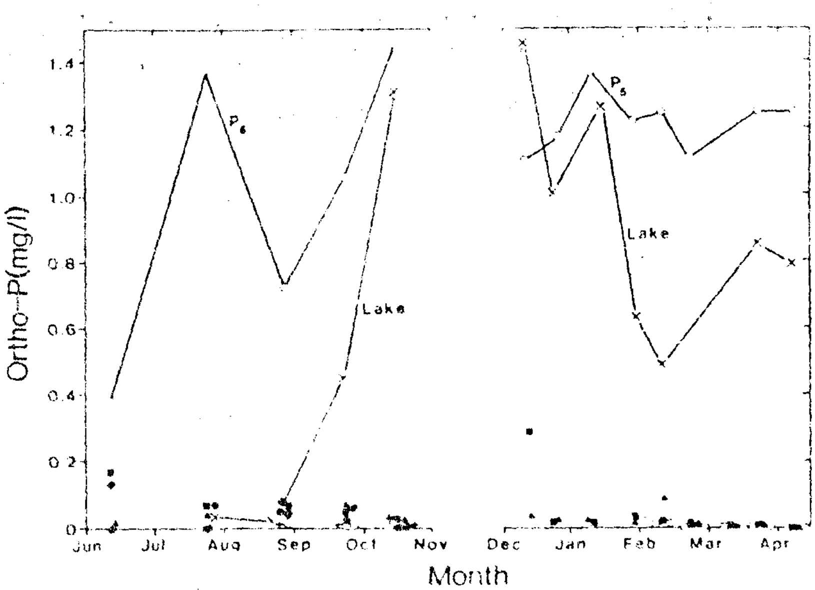
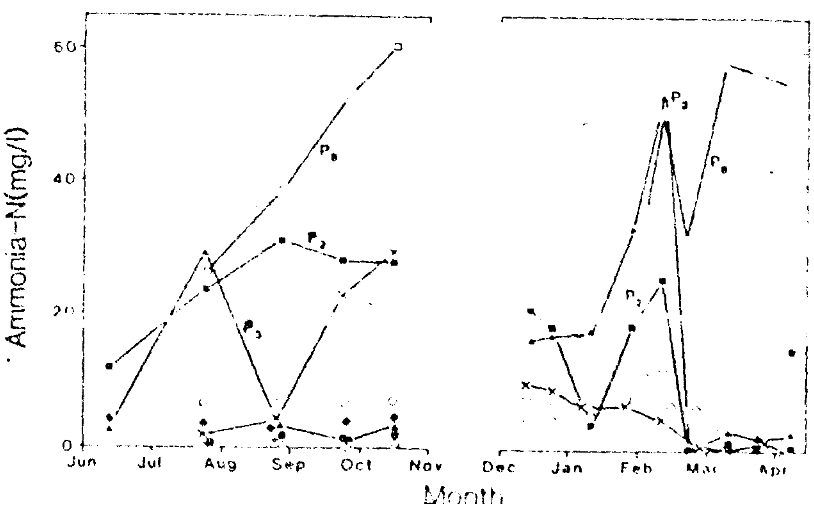


FIGURE 4. ORTHO-P IN WATER SAMPLES

FIGURE 5. AMMONIA-N IN WATER SAMPLES



High levels of ammonia were found in all the bore samples except in P1,P7 and P8 (the controls). The levels are especially high in P2,P3,P6 and lake samples (Figure 5). In general the levels increased from around 10 mg/L or lower in June to above 20 mg/L in August or September. The highest level was in October and had a value of around 60 mg/L.

Despite the above general trend, different concentration patterns were found from one bore to another over time. This was likely to be due to intermittent leachate production from various points below the landfill or at the landfill boundary.

The fluctuation pattern of ammonia-N concentration over time was very close to the COD pattern (Figure 3 and Figure 5). The COD level in all the samples were relatively low (<1200 mg/L). This level of COD indicated that the leachate had undergone Methane fermentation process and/or dilution with groundwater before reaching the monitoring bores. The high pH level of the leachate (higher than 6.7) also indicated the possible existence of a methanogenic activity. Gas samples collected from about 1m below the surface of the landfill indicated high percentage of methane content (Barber, 1986). Comparing the COD levels with rainfall patterns in Perth during the monitoring period (Figure 2), the peak of COD level appeared one or two months after the high rainfall period. This appears to be the time taken by the leachate to flow from the landfill to the monitoring bores.

Phosphate levels were very low (<0.2 mg/L) in all the water samples except in P5 and lake samples where the levels were about 1.2 mg/L. Similar low level of ortho-P was found in leachate from Belmont Tip (Swan River Management Authority, 1982). The soil strata in most of the monitoring bores include peat at the top layer. The low level of Phosphate was probably due to attenuation by this layer. In the case of P5 and lake water samples phosphate movement through the sand layer was probably the reason for the slightly high levels. Increasing level of ortho-P was found in the lake water beginning in September. The level remained relatively high at 1.4 mg/L in October through December. As can be seen from Figure 1, the position of the main lake is such that it is likely to intercept approximately half of the groundwater that flows through the tip site. The presence of a sand layer beneath the landfill facilitates the flow of the leachate into the lake. Unlike peat, the sand layer is unlikely to attenuate phosphate.

The high phosphate level in the lake water coincides with a period of high water table. The highest water level in the lake was observed during the month of October. During that period the lake water was overflowing into the adjacent storm drain and running directly into the river.

6. Conclusion to Leachate Monitoring

Water samples from the monitoring bores near the completed landfill at Guilford road contain considerably high level of ammonia-N (up to 60 mg/L). Some amounts of soluble Phosphate (up to 1.4 mg/L) are present in the lake water and one of the monitoring bores. The contaminated water (leachate) flow into the lake and finally into the river is taking place during the period of high water table (the few months after winter rain). The presence of a sand layer beneath the landfill facilitates the flow of the leachate. The clay bund constructed around the landfill appears to be not very effective in retaining the leachate. However this clay bund may have slowed down the flow of the leachate.

The direction of the groundwater flow at the landfill site indicates that about half of the leachate generated by the landfill flows into the main lake. The other half finds its way into the Swan River by flowing through the ground as evidenced by the presence of ammonia in the monitoring bores. Soil attenuation by a peat or clay layer resulted in low phosphate levels in leachate. However in places where the leachate flowed through a sand layer the phosphate level remained relatively high. Phosphate in the lake and bore P5 is the result of this type of flow.

The flow of leachate decreases in summer and is likely to stop completely toward the end of February. Low levels of ammonia-N in most of the water samples during this time is probably due to the absence of leachate flow.

Nutrient flow into the Swan River only takes place during the period of high water table, potentially from September to January. It would appear to be necessary that this leachate be controlled in order to avoid overloading the river with nutrients. Leachate irrigation seems to be a very appropriate means of control for Perth's dry conditions which cover the period generally from October to May. The water from the lake is of a suitable quality for irrigation water. It has a low COD and salinity levels with high nutrient content.

7. Leachate Irrigation Studies

Two irrigation blocks were prepared for this experiment. One was irrigated with water from the lake and the other one as a control irrigated with water from the Metropolitan Water Supply.

The blocks were sited on the main landfill area, east of the lake. This site was chosen because it was considered necessary that the blocks be located up stream of the groundwater flow so that the associated increase in leachate production would not cause additional leachate pollution. This leachate would flow into the lake and form a cycle through pumping back to the irrigated block.

Irrigation of the blocks was carried out by using Butterfly Springklers. These sprinklers were chosen because they deliver more even water distribution and droplet sizes than other types of sprinklers such as the 'pop up' system or jet system.

Couch grass (Cynodon Dactylon) was planted on both blocks using shredded runners. This type of couch grass was selected because of its good quality and suitability for parks and golf courses. It was expected that the grass would respond to the different types of treatment. The grasses were planted in mid February. After planting, the blocks were divided into 72 smaller plots of $4m^2$. The plots were then grouped into three and treated as follows:

- 24 plots were given full application of fertilizer (400 g per plot),
- 24 plots were given half application of fertilizer (200 g per plot) and
- 24 plots were not given fertilizer

Both block were irrigated twice a day, one in the morning about 10 am for 45 minutes and another one in the evening at 5 pm also for 45 minutes. Each application provided an average of 25 mm water as commonly practise for lawn irrigation in Perth.

The quality of the water in the lake was monitored throughout the irrigation experiment by taking samples every alternate week. The water samples were analysed for their pH, conductivity, total dissolved solids, BOD, COD, ortho-P Ammonia-N and NO_3. These parameters were chosen because of their possible effects on the grasses. Water samples were also taken from the lake and monitoring bores for determination of total plate and faecal coliform counts. This was to see whether the level of count was acceptable for landscape irrigation.

8. Observations and Measurement of Grasses

Ten weeks after the grasses was planted and irrigated, the growth response of the grasses was determined by measuring the length of the runners and weighing the grass after drying.

The block receiving lake water was found to be much greener than the control block. The grasses from all the plots inside the lake water block were found to grow very well and showed no sign of growth inhibition. There was no visual difference in growth response between fertilized plots and non fertilized plots of the lake water block. It was thus concluded that fertilizer application is not necessary for the plot receiving the lake water. Further observations and comparisons were therefore focused on the non fertilized plots of the lake irrigated plots and the controls.

Random samples were taken from the plots with the following treatment:

- Control plots with no fertilizer application,
- Control plots with a full fertilizer application and
- Plots irrigated with lake water and without fertilizer application.

Runner lengths of all the grasses in the selected random plots were measured. After measuring the length, samples of the grasses were carefully dug out by using spade for measurement of root length. The grass was then taken to the laboratory for cleaning from soil particles by carefully rinsing them with tap water and drying in an oven for 24 hours at 105°C. The dried grass was then weight. These data were used for analysis on biomass accumulation.

9. Results and Discussion

Results of the water quality analysis of the lake water are presented in Table 2. Ammonia and COD levels in the lake water during the irrigation experiment (toward the end of the summer period) in general were lower than the levels gefore the summer period. However pH, electrical conductivity and dissolved solids were higher during this period. This high salt content was obviously due to evaporation from the surface of the lake during the dry summer period. Leachate flow from the landfill into the lake during this period was likely to be minimal. COD and ammonia reductions were probably taking place inside the lake. The relatively high pH condition of the lake water was favourable for Ammonia stripping. Nitrification and denitrification was also a possible sink for the ammonium. However, the extent of these processes was not certained.

The quality of the metropolitan water used as control is presented in Table 3.

The water in the lake had an average faecal coliform count of 320 per 100 mL. According to guidelines for reuse of wastewater by the Australian Water Resources Council National Health and Medical Research Council, this level of count is equivalent to class B wastewater (wastewater with faecal

Parameter	Average	Range
pH	8.8	8.2 - 9.4
Conductivity (mS/cm)	3.3	1.7 - 4.6
Total dissolved solids (mg/L)	2710	1100 - 4400
BOD (mg/L)	30	20 - 55
COD (mg/L)	200	136 - 420
Ammonia-N (mg/L)	6.0	0.2 - 9.7
NO_3 (mg/L)	1.2	0 - 2.8
Ortho-P (mg/L)	1.05	0.49 - 2.62
Standard plate (count/100 ml)	3.4×10^5	$(2.4 - 3.5)\times10^5$
Faecal Coliform (count/100 ml)		260 - 380

TABLE 2. THE QUALITY OF LAKE WATER DURING IRRIGATION EXPERIMENT

Parameter	Average	Range
pH	7.4	7.1 - 7.7
Conductivity (mS/m)	74.0	58.9 - 83.2
Total dissolved solids (mg/L)	400	320 - 450
Ammonia-N (mg/L)	< 0.5	n.a
NO_3-N (mg/L)	< 0.5	n.a
Total - P (mg/L)	< 0.05	n.a
Cl (mg/L)	170	130 - 190
Ca (mg/L)	22.6	11.6 - 30.9
Mg (mg/L)	7.8	6.8 - 8.7
Total alkalinity (mg/L $CaCO_3$)	60	41 - 77

TABLE 3. METROPOLITAN WATER QUALITY DURING IRRIGATION PERIOD (DATA FROM WEEKLY SAMPLES COLLECTED FROM MT. YOKINE RESERVOIR OF WATER AUTHORITY WESTERN AUSTRALIA)

coliform count not exceeding median level of 1000 count per 100 mL. This class of wastewater is permitted to be used for landscape irrigation by spraying with public access only after a drying out period.

Despite the relatively lower nutrient and higher salt content of the lake water, the grasses responded with a good growth rate. The average length of the runners in the plot receiving Metropolitan scheme water without addition of fertilizer was 5.9 cm. One application of fertilizer at the rate of 100 g/m^2 immediately after planting was not effective. This was probably due to the effect of heavy rain at the end of February (Figure 2) which probably washed out most of the applied fertilizer from the sandy soil of the irrigation site. Consequently there was not significant difference found between the fertilized plots and the non fertilized plots based on metropolitan scheme water. This problem is a common feature of synthetic fertilizer application in sandy soils.

However the grasses in the plots receiving leachate water from the lake show a significatn difference in length from the grasses in control plots. Statistical analysis on the runners length is summarised in Table 4.

	Plot irrigated with leachate		Control with addition of fertilizer (100 g/m)
Mean runner lengths (cm)	14.4		5.1
Std. deviation (cm)	7.4		3.6
Number of samples	69		40
Difference		9.3	
Standard error of difference		1.06	
Significant difference at		99% level	

TABLE 4. STATISTICAL ANALYSIS OF MEAN LENGTH OF RUNNERS

Results of the dry weight measurements of the grass samples (runners with the root system) indicate that the average dry weight of grass samples from plots receiving leachate water is heavier than the samples from plots receiving Metropolitan scheme water. The mean value of the former was 0.424 g while the mean value of the later 0.117 g. From these values it was found that the biomass accumulation of the couch grass at the end of the 10 week irrigation to be 46.85 g/m^2.This figure is more than double the biomass accumulation in the control plots (21.18 g/m^2).

The difference in the growth respond was obviously due to the influence of nutrients in the leachate water. Even though both irrigation blocks received similar quantities of irrigation water, the growth rate of the grass in the control block was slower. This was probably due to insufficient nutrients in the control block. One application of fertilizer immediately after planting at the rate of 100 g/m^2 was found to have no effect on the growth rate of the grasses in the control plots. Further site preparation work with higher CEC top soil in order to minimise rapid washing out of fertilizer from the irrigated ground may eliminate this problem however it would be expensive. Alternatively much higher fertilizer application is needed if the control plots are to be expected to give similar growth response to the plots receiving leachate water. This is also expensive.

This extra management and expense is not essential for the irrigation of grass if leachate irrigation is used. Knowledge of fertilizer application is not necessary because leachate always contains sufficient nutrients necessary for plant growth, not only the essential nutrients like N and P but also trace elements which may be lacking and frequently are in these sand.

Many types of sites can be used for leachate irrigation work. Sandy soil is potentially the best if the percolated leachate can be recycled back. This is because the sandy soil is less likely to become impermeable as surface ponding was considered to be a problem in the land application of leachate (Barber, 1984). It was also observed in this experiment that the block receiving leachate water took a longer time to become dry after each irrigation than the control block. In some places temporary ponding of leachate water (lasting for about 20 minutes) developed on the block irrigated with leachate water. This was probably due to partial cloging of the soil pores by suspended solids in the leachate. However this ponding was not a problem in this experiment because the permeability of the sandy site remained high.

A large reduction of leachate quantity also takes place in an irrigation site by evapotranspiration. Water requirements for irrigation are generally calculated based on the evaporation rate obtained from a pan evaporimeter. In Perth, the figure is about 1868 mm/year. This is a very high rate as compared to the rate of rain water infiltration. A reasonable estimate of the infiltration rate for a completed landfill site like the study area is about 170 mm/year (calculated based on 20% of the average yearly rainfall). The rate for a natural environment around the area was estimated about 11.5% (Allen, 1981).

Considering leachate as an irrigation water for general soil condition in Perth, the following guidelines as recommended by The Department of Agriculture Western Australia (1982) are to be considered for the calculation of water requirement:

- 100% replacement of water losses for sprinkler irrigation, plus
- 20% increase due to poor water holding capacity of the sandy soil, plus
- 20% for prevention of salt accumulation if the salt concentration in the irrigation water is higher than 500 mg/L.

Due to a generally high salt concentration in leachate, it is considered necessary that a minimal application rate of 140% of the evaporation figure should be used in leachate irrigation. The total requirement calculated on the 140% basis for one year is equal to 2620 mm.

10. Conclusion to Leachate Irrigation Experiment

Leachate recycling for growing grasses is a flexible and practical solution to leachate problem. This method of control is considered very effective for Perth climatic conditions. It is also beneficial because the stabilised leachate is a source of irrigation water and nutrients for plants. The operation of the land irrigation is relatively simple and the irrigated grass can grow very well without the necessity to use complex agricultural practices.

Couch grass (Cynodon Dactylon) irrigated with stabilised leachate was found to grow significantly better than the controls. After a 10 week irrigation the runners have an average length of 14.4 cm while the average for the control was only 5.9 cm. Biomass accumulation in the plots receiving leachate water were more than double the figure from the control plots. It is obvious that the high growth rate of the grass was due to the nutrient content of the leachate water. This consumption of nutrients by the grass ultimately removes the nutrients from the leachate water. The quantity of leachate water will also be reduced by evapotranspiration.

Under Perth climatic conditions, a confined landfill requires less than 10% of the total area for irrigation site. However this pure leachate is too concentrated hence toxic to plants. A big irrigation site is necessary for a landfill situated where there is groundwater intrusion. The size of the site can be calculated from the amount of leachate dilution and an irrigation requirement of 140% of the evaporation rate. In the case of the Bayswater landfill site, the area that can be irrigated with the leachate is about 32%.

The experiment was carried out for a limited period of time. Further studies are needed for testing the long term effect of leachate irrigation on the plants and soils. The reported works elsewhere indicated that there were no harmful effects on plants and soils over a longer period of leachate irrigation (Menser et al., 1979 and Winant et al, 1981). However salt accumulation due to leachate irrigation under dry conditions, as in Perth needs a special consideration.

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