LEACHATE MIGRATION PATH ESTIMATIONS AND GROUNDWATER QUALITY ANALYSIS NEAR A SOLID WASTE DUMPING SITE AT KAMPONG KELICHAP, BATU PAHAT

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BORANG PENGESAHAN STATUS THESIS◆

JUDUL: **LEACHATE MIGRATION PATH ESTIMATIONS AND GROUNDWATER QUALITY ANALYSIS NEAR A SOLID WASTE DUMPING SITE AT KAMPONG KELICHAP, BATU PAHAT**

SESI PENGAJIAN: **2004/2005**

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For

My husband
Md. Rithauddin bin Yatni

&

My parents
Jalil bin Dahlan
Waghaiba binti Hj. Abu Yaman

ACKNOWLEDGEMENT

With the name of Allah, the most gracious and merciful, thanks to Allah for his blessing for the accomplishment of this research. My first appreciation goes to Prof. Ir. Dr. Amir Hashim bin Mohd Kassim for his supervision, concern, and guidance throughout the research progress. It was a great pleasure to conduct thesis under your supervision. My second appreciation goes to Assoc. Prof. Hj. Ab. Aziz bin Abd. Latiff. Thanks for your advices and supports.

I would like to acknowledge Encik Mohamad Faizal bin Tajul Baharuddin, all the lecturers of civil engineering and environmental faculty, technicians of civil engineering and chemistry laboratories, Batu Pahat Municipal Council and Department of Survey and Mapping Malaysia (Segamat) for their great advices, help, and cooperation.

Finally, my special thanks to my husband, Md. Rithauddin bin Yatni, for his concerns, sacrifices, encouragement, and unlimited assistances throughout the research progress. Thank you.

ABSTRACT

The impact of Kampong Kelichap solid waste dumping site on groundwater of an unconfined aquifer was investigated. The investigation involved the analysis of groundwater quality and the estimations of leachate or contaminants movement which included the flow direction and velocity. The leachate or contaminants movement were assumed to be similar to the groundwater movement in the study area. Groundwater level and water quality were monitored from August of 2003 to June of 2004 in nine wells (S1 to S9) located upstream and downstream of the study area. The measured water quality parameters were pH, temperature, turbidity, conductivity, dissolved oxygen (DO), total dissolved solids (TDS), ammonia nitrogen (NH_3-N), sulfate, biochemical oxygen demand (BOD_5), and chemical oxygen demand (COD). Contaminants concentration distribution in groundwater has been mapped or contoured using geostatistical analysis. Groundwater and contaminant movement or flow characteristics were estimated using water table contours, correlation surface analysis, and numerical models. The numerical modeling was conducted by using MODFLOW in conjunction with MODPATH and MT3D. Field and laboratory results showed high concentrations of conductivity, COD, NH_3-N and TDS in the downstream groundwater. Field measurements, laboratory analyses, and simulated models showed similar results in which the contaminated wells were S3, S4, S5, and S6. Conductivity, COD, and NH_3-N concentration contours suggested the dumping site as the main source of groundwater contamination in the study area. The changes in the patterns on COD concentration contours, the water table contours, the correlation surface analysis, and the numerical models showed that the contaminants and groundwater were traveling mainly toward the southwestern boundary with an average direction of 196 °, 199.5 °, 242.7 °, and 228.4°, respectively, as measured clockwise from the north. The estimated contaminated groundwater velocities from the correlation analysis and numerical model were ranging from 315.5 to 359 m/yr and 174 to 284 m/yr, respectively.

ABSTRAK

Kesan tapak pelupusan sampah Kampung Kelichap ke atas air bumi di dikaji. Kajian ini meliputi analisis kualiti air bumi (akuifer tak terkurung) dan anggaran arah dan halaju pergerakkan air kurasan atau bahan pencemar. Pergerakkan air kurasan atau bahan pencemar dari tapak pelupusan sampah tersebut di andaikan menyerupai pergerakan air bumi di kawasan kajian. Aras air bumi dan kualiti air bumi di ukur mulai Ogos, 2003 sehingga Jun, 2004 di sembilan buah telaga (S1-S9) yang terletak di hulu dan di hilir kawasan kajian. Parameter-parameter kualiti air yang dikaji adalah pH, suhu, kekeruhan, konduktiviti, oksigen terlarut, ammonia nitrogen (NH_3-N), sulfat, keperluan oksigen biokimia (BOD_5) dan keperluan oksigen kimia (COD). Pemetaan taburan kepekatan bahan pencemar di dalam air bumi di kawasan kajian di lakukan melalui analisis geostatistik. Pergerakan air bumi and bahan pencemar di anggarkan menggunakan kontur paras air bumi untuk akuifer tak terkurung, analisis korelasi, dan model simulasi. Model simulasi dilakukan menggunakan MODFLOW bersama dengan MODPATH dan MT3D. Air bumi yang terletak di hilir kawasan kajian didapati mengandungi kepekatan konduktiviti, COD, NH_3-N dan TDS yang tinggi. Hasil kerja lapangan, makmal and model simulasi menunjukkan bahawa telaga yang telah dicemari air kurasan dari tapak pelupusan sampah tersebut adalah S3, S4, S5, dan S6. Corak taburan konduktiviti, COD, dan NH_3-N mencadangkan tapak pelupusan sampah tersebut sebagai punca pencemaran utama air bumi di kawasan kajian. Perubahan corak taburan kepekatan COD, kontur paras air bumi, analisis korelasi, dan model simulasi menunjukkan aliran utama bahan pencemar dan air bumi adalah ke arah sempadan baratdaya masing-masing dengan purata arah yang diukur mengikut arah jam dari utara, 196 °, 199.5 °, 242.7 °, dan 228.4 °. Halaju air bumi tercemar yang terhasil melalui analisis korelasi dan model simulasi masing-masing adalah di dalam lingkungan 315.5 hingga 359.2 dan 174 hingga 284 m/yr.

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LIST OF ABBREVIATIONS

BOD	-	Biochemical oxygen demand
CB	-	Background concentration of an element
Cd	-	Cadmium
CF	-	Contamination factor
CM	-	Concentration of an element measured in a determined sample
CH_4	-	Methane
CO_2	-	Carbon dioxide
COD	-	Chemical oxygen demand
Cu	-	Copper
Cr	-	Chromium
$Cr_2O_7^{2-}$	-	Dichromate ion
Cr^{3+}	-	Chromic ion
DO	-	Dissolved oxygen
EC	-	Electrical conductivity
FTU	-	Formazine turbidity unit
Fe	-	Iron
Geotrans	-	Geographic translator software developed by NIMA
GMS	-	Groundwater modeling system
GPS	-	Global Positioning System
MODFLOW	-	USGS groundwater flow simulation code
MODPATH	-	Particle tracking post-processing package
Mn	-	Manganese
MSE	-	Mean squared error
MT3D	-	A modular three dimensional multi species transport model
NH_3-N	-	Ammonia nitrogen
Ni	-	Nickel
NIMA	-	National Imagery and Mapping Agency

NTU	-	Nephelometric turbidity unit
PAEE	-	Percentage average estimation error
Pb	-	Lead
RMSE	-	Relative mean squared error
TDS	-	Total dissolved solids
TSS	-	Total suspended solids
USGS	-	U.S. Geological Survey
WHO	-	World Health Organization
Zn	-	Zinc

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CHAPTER I

INTRODUCTION

Comprising, over 70 percents of earth surface, water is undoubtedly the most precious natural resources that exists on our planet. Oceans contain 97 percent of the earth's water while the remaining three percents is classified as fresh water and 95 percents of all fresh water on earth is groundwater. In United States, approximately 50 percents of the population relies on groundwater as a source of drinking water. In Malaysia, the use of groundwater for domestic purposes is mainly confined to rural area where piped water supply is not available. Groundwater is being significantly utilized in Kelantan and Perlis and other states that supplement the water supply systems with groundwater are Pahang, Terengganu, Sabah and Sarawak. In peninsular Malaysia, 60 percents of the exploited groundwater is used for domestic, 35 percents for industrial and 5 percents for agricultural purposes.

Population growth, industrial or agricultural expansion, deterioration in surface water quality and low flow of surface water during prolonged drought has increased the demands of water sources. The increase in the demands for water sources has increased the need for more systematic and sustainable exploration of the groundwater. However, groundwater resources are exposed to pollutions due to human activities and as shown in Figure 1.1, landfill is one the major threats to the groundwater quality.

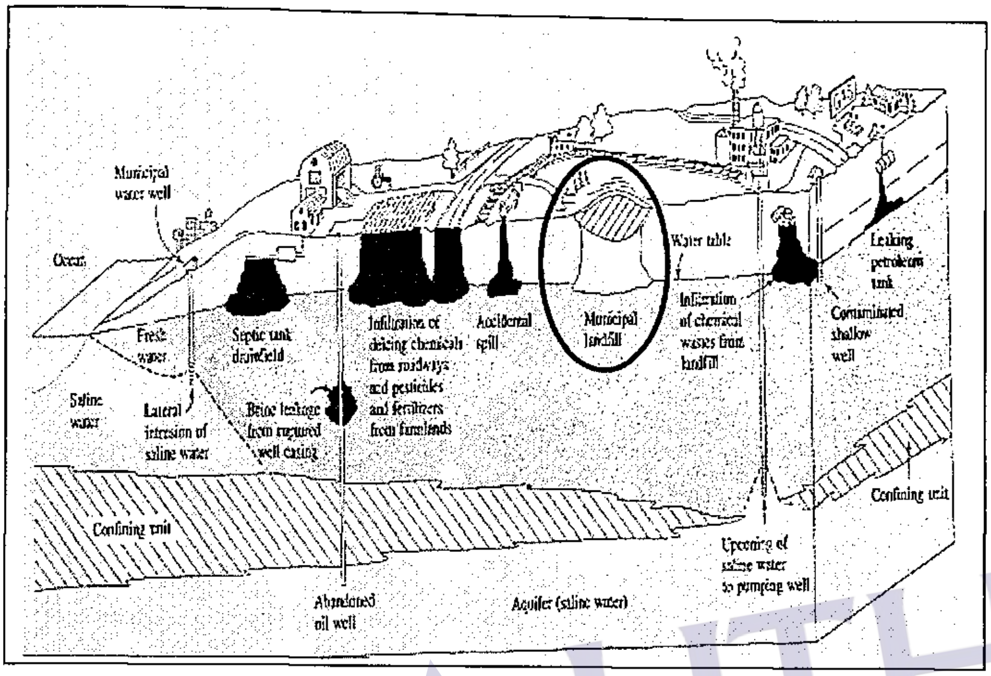


Figure 1.1: Mechanisms of groundwater contamination (Fetter, 1999)

Contaminated groundwater may pose a serious threat to health and as reported in Berita Harian of 21st February of 2005, the consumption of contaminated groundwater may have been the cause of the death of a five years old child in Kuala Ketil Kedah, Malaysia. Also, the purification of the contaminated groundwater may take centuries and the expenditure of a huge sum of money. These facts alone make it imperative that the contamination of groundwater must be avoided to the maximum possible extent.

1.1 Research Background

Waste generation rate in Malaysia has increased with the increase in the number of population. In 1993, Malaysia's urban population had generated about 5.2 million tons of solids waste or equivalent to 0.34 – 0.85 kg/capita/day (Chai and Zakaria, 2004) and in Malaysia, only three percents of the glass materials and papers were recycled (Agamuthu, 2001). The national average generation rate estimated for

1991 to 1994 was about 0.71kg/capita/day and this figure has increased to about 1 kg/capita/day in the year 2000 (Engku, 2000).

In Malaysia, landfill is a common technique used for the solid waste disposal. A landfill can be any area of land used for deposit of solid wastes and it includes open or covered dumps in depressed area to well designed, constructed and operated sanitary landfills. Some landfills are unlined and to have waste emplaced near the water table or contacting the groundwater at higher water levels. Since landfill is the least expensive waste management option, it may continue to be the primary method of solid waste disposal for many years in the future.

The major environmental concern associated with landfills was related to the discharge of leachate into the environment and the most detrimental effect of leachate discharge into the environment is that of groundwater pollution (Christensen et al., 1992). Leachate can be formed when rain is falling or snow is melting over a landfill and the water seep into the landfill. Leachate can also be formed from the liquid found in the wastes (Fetter, 1999). Landfill leachate can contaminate water sources with organic chemicals when released into the environment. These organic chemicals were normally fluids that created a health hazard for human and animal life.

In the late 1970's, tests revealed that the quality of groundwater below certain poorly constructed landfills was unsafe for human consumption. Researchers then realized that the contaminated groundwater came from the movement of leachate from the landfill to the groundwater. Landfill leachate was found to migrate downwards, reached the water table, mixed with the groundwater system, and followed the groundwater flow towards the downstream area. The illustration of an idealized leachate plume and the geochemical zonation are shown in Figure 1.2.

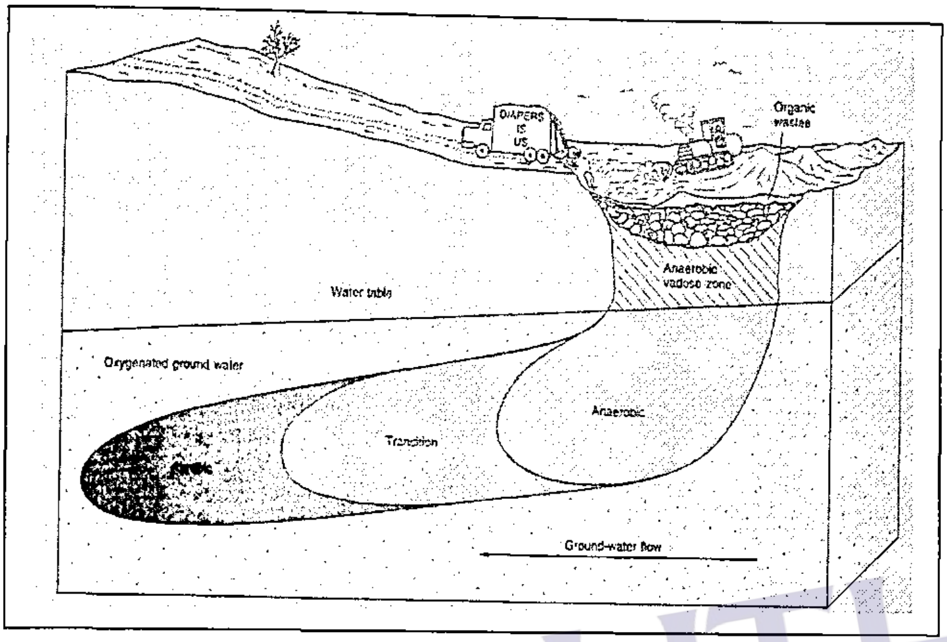


Figure 1.2: Geochemical zonation of the leachate plume from a landfill receiving organic waste (Fetter, 1999)

1.2 Study Area

The present study has been conducted at an area near the Kampong Kelichap solid waste dumping site, which is located in the district of Batu Pahat, state of Johor, Malaysia. The study area is lying about 16 km south of the Batu Pahat town and it covers an area of approximately 1 km^2 of the Kampong Kelichap. The location of the study area is shown in Figure 1.3. The geological map of the study area is shown in Figure1.4. From the geological map by the Geological Survey Department, Malaysia (1985, now the Mineral and Geoscience Department), the quaternary deposits of the study area consisted of clay and silt marine and sand mainly marine. The climate of the study area is tropical equatorial and is characterized by uniform temperature and high rainfall. The annual rainfall amount for Batu Pahat for the years of 1993 to 2001 is shown in Appendix B (table 21), which varies from 1358 to 2811mm. The monthly rainfall amount for August of 2003, November of 2003, March of 2004, and May of 2004 are shown from the rainfall map of peninsular Malaysia shown in Figure 1.5.

Figure 1.3: Location of the study area (indicated by red star)

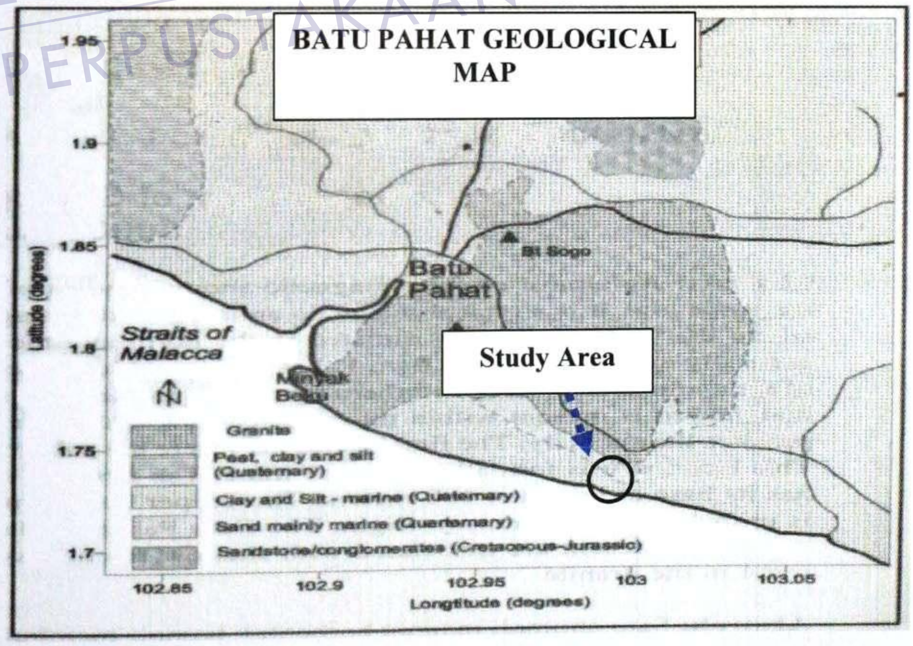


Figure 1.4: Geological map of Batu Pahat (GMS after 1985)

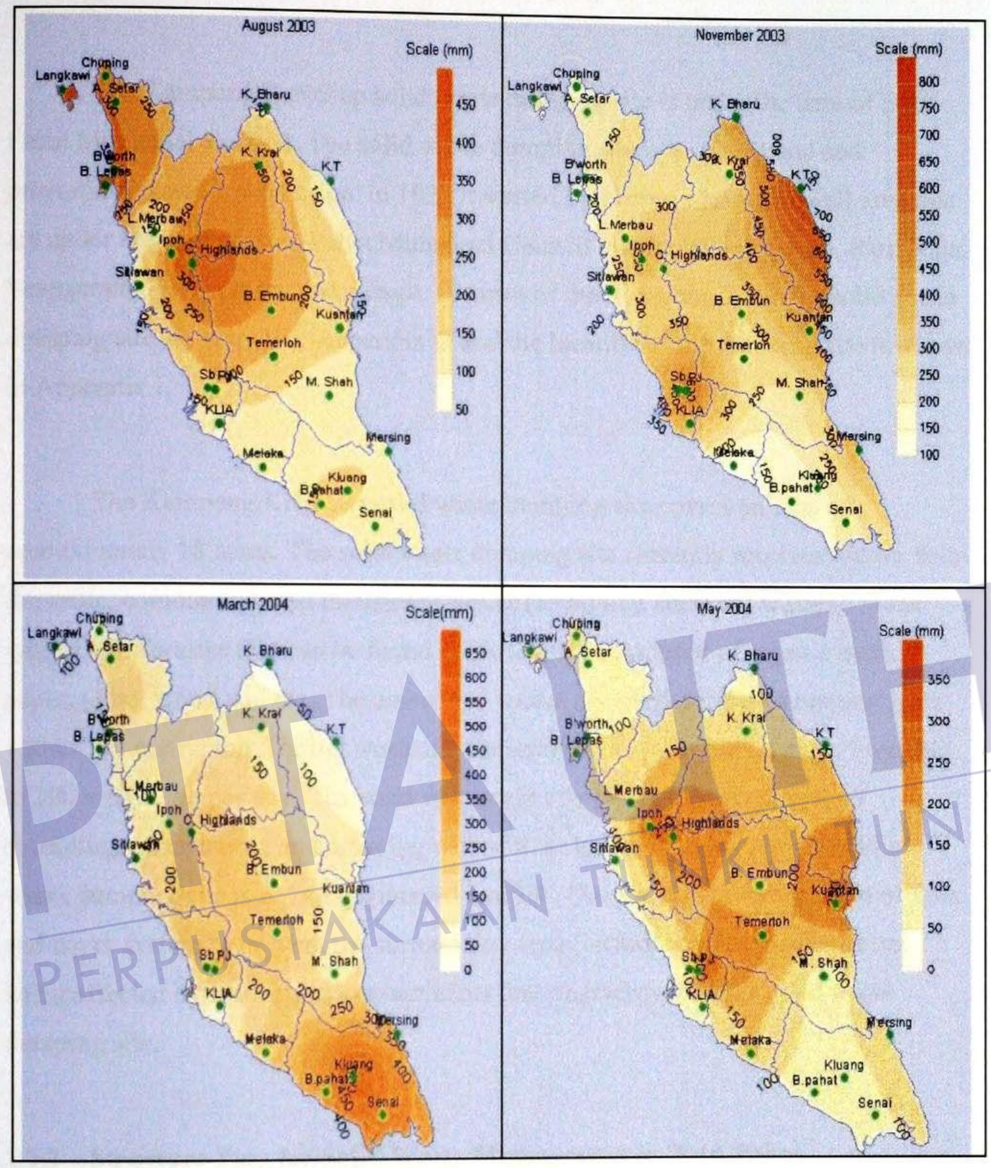


Figure 1.5: Rainfall map for peninsular Malaysia (Monthly Weather Bulletin, Meteorological Service of Malaysia, 2003 & 2004)

1.2.1 Kampong Kelichap Solid Waste Dumping Site

The Kampong Kelichap solid waste dumping site is under the care of Batu Pahat Municipal Council. The solid waste dumping site is an active site and previously, it was a sand mine. In 1997 it started to receive wastes from all area that are under the care of Batu Pahat Municipal Council that include Semerah, Parit Raja, Senggarang, Penggaram, and Rengit. Pictures of the Kampong Kelichap solid waste dumping site are shown in Appendix G and the location of the dumping site is shown in Appendix I.

The Kampong Kelichap solid waste dumping site covers an area of approximately 18 acres. The solid waste dumping site currently receives wastes from domestic, commercial, and industrial sources (excluding chemical wastes). Some typical solid wastes that can be found at the site are composed of organic matter, paper, glass, wood and etc. The amount of wastes received per day is ranging from 150 to 200 metric ton. During weekend, the amount of waste can increase from 200 to 300 metric ton per day. The solid wastes are disposed by the technique of spreading, compacting, and covering with soil. In terms of technology, the solid waste dumping site is not an engineered landfill. There is no implementation of liner and cover system to prevent the surrounding area (including water bodies) from being affected by leachate or contaminants that migrating from the solid waste dumping site.

1.2.2 Structure Plan for Solid Waste Management in Batu Pahat

Waste generation rate is expected to increase with the increasing number of population in Batu Pahat. This increasing amount of waste has been considered for the improvement of solid waste management as indicated in the draft of the structure planning for Batu Pahat District for the years of 2002 to 2020. The improvement plan includes the implementation of new dumping sites and solid wastes transfer stations.

Four new locations have been considered for the placement of the new solid waste dumping sites. The new locations are at Jalan Tanjong Laboh, Koris, Tongkang Pechah, and Ladang Yong Peng, as shown in Appendix J. The locations were selected based on the guidelines for planning and managing solid wastes that include economical, physical, social, and environmental aspects. Each of the new dumping sites is expected to receive wastes from the total of 30 000 population and from an area that is within 10 km from the dumping site area. With the implementation of the new dumping sites, problems in managing large amount of wastes that can no longer be disposed in the Kampong Kelichap solid waste dumping site are expected to be solved. The Kampong Kelichap solid waste dumping may have to be close in few years from now.

1.3 Problem Statements

The bottom part of the Kampong Kelichap solid waste dumping site was not lined and according to Kayabali et al. (1998), groundwater in the vicinity of an unlined landfill could be contaminated by landfill leachate. Leachate or contaminants from the dumping site, therefore, may have been infiltrated downward and mixed with the groundwater system and thus contaminating it. Leachate samples from the Kampong Kelichap solid waste dumping site were shown to contain large amount of contaminants such as BOD_5, COD (Abdul Hamid, 2004), Mn, Cu, Zn, and Fe (Abdul Rahim, 2004). At present, there is almost no study has been reported on the effect of the solid waste dumping site on the groundwater of Kampong Kelichap and there is almost no information on the chemical characteristics of the groundwater in the vicinity of the Kampong Kelichap solid waste dumping site.

Surrounding the solid waste dumping site area, there are dug wells that previously used as main water supplies. At present, even though drinking water is obtained mainly from piped water supply, groundwater is still consumed by some residents that live at the northern part of the study area. Since there are possibilities that contaminants from the dumping site have been introduced in the groundwater system, it is a matter of great urgency to estimate where the contaminants are traveling. If the contaminants are found to travel toward the dug wells, it is also a matter of great urgency to estimate when the contaminants will reach the wells. At present, there is almost no information on leachate or contaminants migration path and rate in the study area. In addition to the dug wells, at the southern part of the study area, there are ponds that currently used for fishery activities. It is also important to estimate if the underground transport of contaminants from the dumping site is heading toward the ponds.

1.4 Importance of the Study

Based on the problem statements, the present study is important because public health is the main concern. If the groundwater is found to have been affected by leachate and constitute large amount of contaminants, and if the contaminated groundwater is traveling toward certain wells at certain velocity, the wells may have to be abandoned. The products of present research can be used by government agencies such as Batu Pahat Municipal Council and Department of Environment to manage any remedial action if necessary. The findings can also serve as basic references for future study on landfill leachate, groundwater contamination and contaminant migration from a landfill site.

1.5 Research Objective

There are two objectives in the present study. The first objective was to determine if the groundwater of the study area was affected by leachate that migrating from the Kampong Kelichap solid waste dumping site. The second objective was to estimate the direction and velocity of leachate or contaminants movement from the dumping site based on groundwater movement estimations.

1.6 Scopes

In order to meet the research objectives, the scopes of the study are listed below.

a. Bore wells were installed around the dumping site.

b. Field works that consisted of in situ measurement and soil, surface water and groundwater samplings were conducted.

c. Chemical characteristics of the water samples were also obtained through laboratory works.

d. Maps or contours of contaminants distribution in the study area were obtained through kriging interpolation technique.

e. Leachate or contaminants movement were estimated based on groundwater movement estimations using water table contour, correlation surface analysis and numerical model.

1.7 Assumptions

The assumptions of the present study are listed below.

a. Groundwater contamination was assumed to be mainly caused by the underground transport of contaminants from the solid waste dumping site. The effect of surface run off was not considered.

b. The saturated porous medium was assumed to be homogeneous and isotropic throughout the study area.

c. The movement of leachate or contaminants from the dumping site was assumed to be similar to the movement of groundwater in the study area. This assumption was made based on the findings of Samsudin et al. (1999) and Ahmed and Sulaiman (2001), who concluded that the flow of contaminants or leachate from two landfills in Malaysia (Gemencheh and Seri Petaling landfill, respectively) followed the groundwater flow toward the downstream area. Also, according to Gurunadha et al. (2001), the density and viscosity of the contaminated groundwater were nearly the same as those of the uncontaminated groundwater in Medak district, Andhra Pradesh, India.

1.8 Thesis Layout

This thesis consisted of six chapters written comprehensively in accomplishing the objective of the present study which comprised of literature review and theoretical background, research methodology, results and discussions and conclusion.

Chapter II discusses the literature review and theoretical background of the present study. In order to determine the impact of solid waste disposal on groundwater or to identify the presence of leachate in the groundwater, to present the contaminants spatial distributions, and to estimate the leachate migration path and direction, previous studies as early as 1980 were reviewed.

Field and laboratory works and method of data analysis are described in Chapter III. This chapter provided a precise elaboration on standard of testing applied, specifications of apparatus involved, technique of kriging interpolation, correlation surface analysis and numerical modeling using MODFLOW, MODPATH, and MT3D.

The results of the field and laboratory analyses and also the produced contaminant concentration contours are presented in Chapter IV. Graphs were plotted using Excel and data were analyzed statistically. The results of sieve analysis and groundwater and leachate or contaminant movement are described in Chapter V. The movement estimations have been conducted using water table contour, correlation surface analysis and numerical modeling.

Chapter VI summarized and concluded the present study based on the research findings and discussions.

CHAPTER II

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Introduction

This chapter consisted of the review of previous findings on the chemical characteristics of landfill leachate and the adverse impacts of landfill leachate to groundwater. Basic groundwater hydrology and theories of leachate and groundwater movement were also included in this chapter. The methods of investigation and the techniques of data analysis were also reviewed. The review on the data analysis included the application of geostatistics for contouring contaminants concentration distribution, application of correlation surface analysis for estimating groundwater and leachate or contaminant movement, and numerical modeling for simulating groundwater flow and contaminant transport.

2.2 Landfill Leachate

Dumping sites for municipal wastes usually produce leachate that migrates to adjacent areas, resulting in gross pollution of soil, surface water and groundwater (Bocanegra et al., 2001). The liquid portion of leachate is composed of both the liquid produced from the decomposition of the wastes and liquid that has entered the landfill from external sources, such as surface drainage and rainfall. When water or rainwater percolated through the decomposing solid wastes, both biological materials and chemical constituents are picked up. Matter that was resistant to biological or chemical changes, which could remain in the soil for many years, might also present in landfill leachate (Bocanegra et al., 2001).

Metals were among the chemical constituents present in landfill leachate. In municipal landfill leachates, metals were usually found at moderate concentration levels and typical values were in the range of: Cd 2-20μg/L, Ni 100-400μg/L, Zn 500-2000μg/L, Cu 20-100μg/L, Cr 100-500μg/L and Pb 50-200μg/L (Jensen and Christensen, 1999). In the works of Abdul Rahim (2004), however, higher concentration levels of Cu and Zn were found in leachate samples from Kampong Kelichap solid waste dumping site. Table 2.1 shows some of the chemical constituents present in leachate samples from the Kampong Kelichap solid waste dumping site.

Table 2.1: Chemical characteristics of leachate samples from Kampong Kelichap solid waste dumping site

Parameters (mg/L)	Abdul Hamid (2004)	Abdul Rahim (2004)
Total suspended solid (TSS)	285	nr
COD	1767	nr
BOD_5	641	nr
Mn	nr	25.68
Cu	nr	30.42
Zn	nr	10
Fe	nr	28.6

Note: nr-not reported

The compositions of landfill leachate at different sites were shown to be variable (Jensen &Christensen, 1999; Fatta et al., 1999; Lo, 1996; Mohammad et al., 2004; Muttamara & Leong, 1997). The differences in the composition of landfill leachate were due to the differences in waste composition, landfilling technology, and site conditions including pH, temperature, moisture content, landfill age and climate. Chemical characteristics of leachate according to the age of landfill are shown in Table 2.2 and leachate constituents from various sources are shown in Table 2.3. Rainfall was also shown as a factor that controls leachate composition. Previous studies had shown that the composition varied due to different dilution rates caused by rainfall (Kayabali et al., 1998; Muttamara & Leong, 1997).

Table 2.2: Landfill leachate chemical characteristics according to age (Amokrane et al., 1997)

Landfill Age (years) Leachate Type	< 5 (young) I (biodegradable)	5-10 (medium) II (intermediate)	>10 (old) III (stabilized)
pH	<6.5	6.5-7.5	>7.5
COD (g/l)	>10	<10	<5
BOD_5/COD	>0.5	0.1-0.5	<0.1

2.3 Landfill Leachate and Its Impact on Groundwater

Leachate migrations from wastes site or landfills and the release of pollutants from sediment (under certain conditions) pose a high risk to groundwater resource if not adequately managed (Ikem et al., 2002). A great number of studies have been prompted by the adverse impacts of landfill leachate on the groundwater. These included the studies of landfill leachate intrusion in groundwater by Kayabali et al. (1998), Fatta et al (1999), Ahmed & Sulaiman (2001), Ikem et al. (2002), and Mizumura (2003). Among those studies, the route and sources of leachate plume into the ground were described by Mizumura (2003). The general trend of groundwater contamination due to the solid waste disposal site was shown to be toward the downstream area (Fatta et al., 1999; Samsuddin et al., 1999; Ahmed & Sulaiman, 2001). Table 2.3 presents the chemical characteristics of the landfill leachate contaminated groundwater.

Table 2.3: Chemical characteristics of landfill leachate and groundwater of an area near a landfill (all in mg/l unless specified).

Sources		COD	TDS	EC (µS/cm)	Sulfate	NH_3-N	pH
Chen and Wang (1997): Leachate		335-1996	nr	nr	nr	nr	7.2-7.43
Lee et al. (1997):	Leachate	663-4052	5721-9861	16598-24785	69.2-90	nr	8.0-8.5
	Groundwater	22-325	332-5178	561-12755	16.4-44.6	nr	7.1-8.9
Ikem et al. (2002):	Leachate						
	Groundwater	3.1-5-85.8	699.9-2324.7	nr	nr	nr	7.21-8.05
		0.28-3.32	83.93-489				4.99-7.68
Fatte et al. (1999):	Leachate						
	Groundwater	3812-6125	7934-16340	22220-26900	192-758	1000-1350	8.07-8.63
		35.8-78	246-2170	723-4470	15-112	0.93 to 67.8	7.16-7.49
Amokrane et al. (1997): Leachate		4100	nr	nr	550	nr	8.2
Lo (1996):	Leachate						
	Closed Landfill sites	750-50000	nr	20000-25000	7-1000	2000- 13000	7.1-9.0
	Active Landfill sites	6610-30000		20000	19-440	760-11000	5.6-9.1
Ahmed and Sulaiman (2001): Groundwater		nr	nr	7160	3.57	nr	8.05
Mohammad et al. (2004): Leachate		6184-8848.5	nr	16481-31383.1	nr	6086-8751.6	6-7.9

Note : nr – not reported

2.4 Physical and Chemical Characteristics of Landfill Leachate and Landfill Leachate Contaminated Groundwater.

Turbidity, conductivity, pH, temperature, and dissolved oxygen were among *in situ* parameters measured in the field for the characterization of leachate and leachate contaminated groundwater. In laboratory, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), ammonia nitrogen, and sulfate were normally analyzed to provide a general characterization of the landfill leachate and to indicate its (leachate) presence in groundwater system.

2.4.1 Temperature

The measurement of temperature was one of the most important since it was a controlling variable (Sanders, 1998). Many geochemical properties such as mineral and gas solubility were temperature sensitive (Deutsch, 1997). The temperatures of landfill leachate (Muttamara & Leong, 1997; Mohammad et al., 2004; Agamuthu, 2001; Tang, 1998) and landfill leachate contaminated groundwater (Lim, 1999; Lee et al., 1997) were ranging between 25.1 and 35.5°C.

2.4.2 pH

Measurement of pH was one of the most important and frequently used tests in water chemistry. Many of solution processes (aqueous complexation), water/rock interactions (mineral solubility and adsorption properties), gas solubilities, and biochemical reactions were pH sensitive (Deutsch, 1997). The pH of landfill leachate could indicate the stage of solid waste decomposition involved in a landfill site. An acidic pH indicated that the landfill was in an aerobic stage in which leachate with an unpleasant smell was produced (Lo, 1996; Fatta et al., 1999). pH around or slightly above neutral indicated that the landfill was in methanogenic phase, which was by far the longest and most important phase (Fatta et al., 1999; Christensen et al., 2001).

2.4.3 Conductivity

High conductivity values indicated the existence of high amounts of soluble inorganic pollutants (Kayabali et al., 1998). High conductivity values were found in leachate of Malaysian landfills (Agamuthu, 2001; Mohammad et al., 2004) and of countries such as Hong Kong, Korea, and Greece (Lo, 1996; Lee et al., 1997; Fatta et al., 1999). The presence of leachate in groundwater system was also indicated by high conductivity values observed downstream to landfill sites (Kayabali et al., 1998; Ahmed & Sulaiman, 2001; Fatta et al., 1999).

2.4.4 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) comprised of the sum of total contaminants and it can be measured as an indicator of contamination. TDS, if present in sufficient amount, could cause severe degradation of groundwater quality and preclude its use for domestic water supply purposes (Lee et al., 1993). Also, its distribution could be taken as an overall contaminant migration (Shivkumar et al., 1997; Gurunadha et al., 2001).

Leachate with total dissolved solids concentration of 20000 mg/L was not uncommon (Christensen et al., 2001). As reported by Ikem et al. (2002), TDS concentration in leachate and groundwater samples of two waste sites in Nigeria were ranging from 700 to 1922 mg/L and 80 to 492 mg/L, respectively. Higher TDS concentrations were found in leachate and groundwater of a waste site in Greece that were ranging from 8334 to 17000, and 246 to 2170 mg/L, respectively (Fatta et al., 1999).

2.4.5 Dissolved Oxygen (DO)

Dissolved oxygen or DO was a measure of the amount of oxygen freely available in water. DO levels in wastewater depended on physical, chemical, and biochemical activities in the water body. As reported by Ekpo et al. (2000), low DO concentration in leachate of Calabar Municipality landfill might indicate high microbial populations that might have enhanced the decomposition of organic waste while high value of DO (above WHO standard of 4.0 mg/L) indicated that the groundwater was not polluted by organic waste. For groundwater downstream to Seri Petaling landfill, the reported DO was 5.08 mg/L (Ahmed & Sulaiman, 2001).

2.4.6 Turbidity

Turbidity was an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. Turbidity in water caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms.

Turbidity values of leachate samples from Danish landfills (Jensen & Christensen, 1999) and from old and new waste sites in Nigeria (Ekpo et al., 2000) were ranging from 2.5 to125 NTU, 1245 to 2002 FTU and 1005 to 2000 FTU, respectively. Turbidity values of groundwater samples from the vicinity the old and new waste sites in Nigeria were ranging from 8 to 10 FTU and 0 to 4 FTU, respectively (Ekpo et al., 2000).

2.4.7 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand or BOD test was normally conducted to determine the relative oxygen requirements of waste waters, effluents, and contaminated waters. The BOD test measured the oxygen utilized during a specified incubation period for the biochemical degradation or organic material and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron. It might also measure the oxygen used to oxidize reduced forms of nitrogen unless their oxidation was prevented by an inhibitor. Five days BOD test (BOD_5) was normally used for the characterization of leachate or leachate contaminated groundwater.

According to Ekpo et al. (2000), high BOD_5 concentration could be caused by a high rate of microbial degradation of organic waste enhanced by high temperature while lower BOD_5 concentration could be due to the presence of contaminants that limit or prevent microbial respiration. For leachate sample from the Kampong Kelichap solid waste dumping site, the measured BOD_5 concentration was 641 mg/L (Abdul Hamid, 2004).

2.4.8 Chemical Oxygen Demand (COD)

Among the constituents of leachate, chemical oxygen demand or COD was one of the most common components, traditionally analyzed to provide an overview characterization of leachate. The analysis of COD could be carried out using HACH DR 2000 Spectrophotometer (Mohammed et al., 2004). COD was typically present in elevated concentrations in landfill leachate (Amokrane, 1997; Tang, 1998, Agamuthu, 2001; Mohammad et al., 2004; Lo, 1996; Muttamara & Leong, 1997; Fatta et al., 1999; Lee et al., 1997) and could often indicate the presence of leachate in groundwater (Lee et al., 1993; Fatta et al., 1999; Lim, 1999).

The high amount of COD in landfill leachate was due to the formation and degradation of fatty acid (Mohammad et al., 2004). COD consisted of both biodegradable and nonbiodegradable materials and during chemical oxidation, both biodegradable and resistant substances were being oxidized. The high amount of COD in leachate, therefore, indicated that leachate from a solid waste disposal site must contain a high number of chemical components (Muttamara & Leong, 1997).

Leachate of Malaysian landfills was shown to contain high concentration of COD (Tang, 1998, Agamuthu, 2001; Mohammad et al., 2004). The measured COD concentration of leachate samples from Kampong Kelichap solid waste dumping site was 1767 mg/L (Abdul Hamid, 2004). High concentration of COD was also found in Hong Kong, Thailand, Greece and Korean leachate (Lo, 1996; Muttamara & Leong, 1997; Fatta et al., 1999; Lee et al., 1997). As shown in the works of Lim (1999) and

Fatta et al. (1999), high concentration of COD in landfill leachate had an impact on groundwater quality.

2.4.9 Ammonia Nitrogen (NH_3-N)

High concentration of ammonia nitrogen (NH_3-N) was normally found in landfill leachate and landfill leachate contaminated groundwater. The high concentration of ammonia was due to the anaerobic conditions that prevailed in a landfill which in return contributed to nitrate reduction towards ammonia gas phase. High concentrations of ammonia were very toxic to the microorganisms that were responsible for anaerobic processes and hence inhibit their growth and activity (Fatta et al., 1999).

Leachates from Taman Berigin (Tang, 1998) and Ampang (Agamuthu, 2001) landfill in Malaysia were reported to contain high amount of NH_3-N. The high concentration of NH_3-N in the leachate of Taman Beringin landfill reflected active and continuous refuse degradation inside the landfill (Tang, 1998). The NH_3-N concentration after the closure of the Ampang landfill was reported at 690 mg/L. High concentration of NH_3-N was found in leachate samples from landfills in Korea (Kaur et al., 1996), Hong Kong (Lo, 1996) and Greece (Fatta et al., 1999) and the concentration was ranging from 662.7 to 1400 mg/L, 2000 to 13000 mg/L and 1000 to 1350 mg/L, respectively. High concentration of NH_3-N in groundwater downstream to Seri Petaling (Lim, 1999) and Greece (Fatta et al., 1999) landfill with an average value of 75 mg/L and 0.93 to 67.8 mg/L, respectively, indicated the presence of leachate in the groundwater system.

2.4.10 Sulfate

Sulfate has been detected at elevated concentrations in landfill leachate as reported by Lo (1996) and Amokrane (1997). However, low concentrations of sulfate were more common in landfill leachate (Agamuthu, 2001; Lee et al., 1997) and landfill leachate contaminated groundwater (Ahmed & Sulaiman, 2001; Ikem et al.

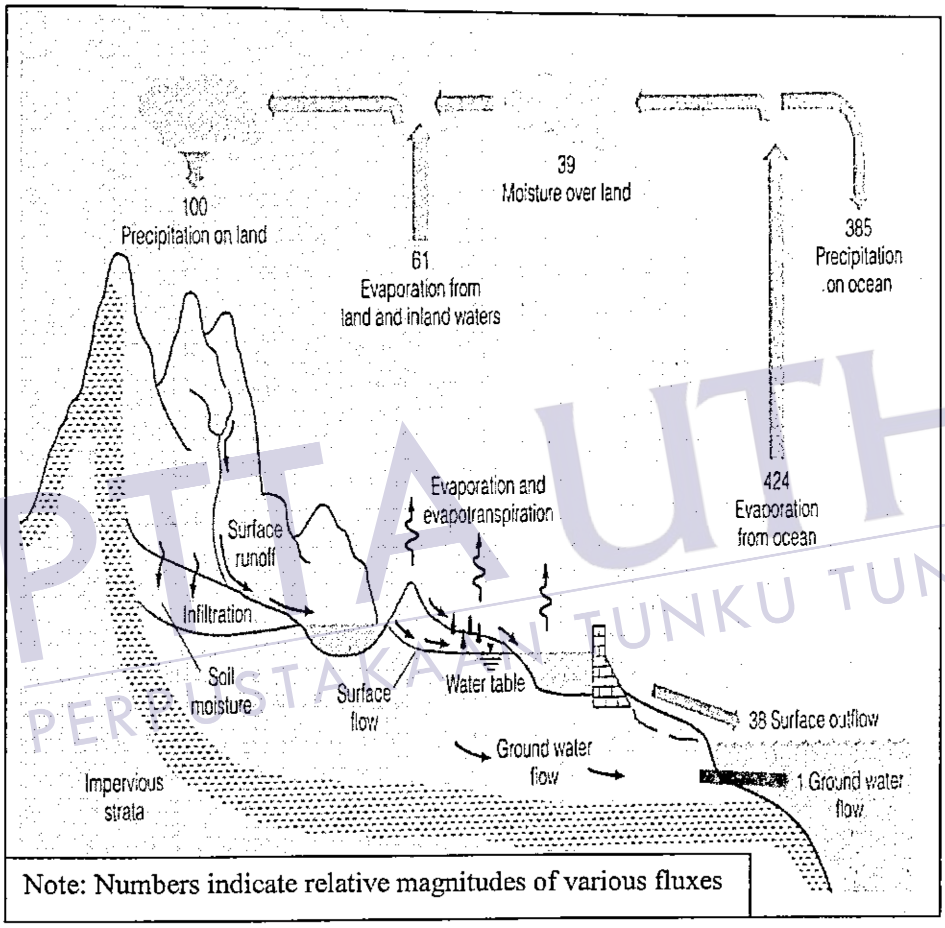
2002; Lee et al., 1997). Low concentration of sulfate was found in leachate sample from Air Hitam, Berigin and Sabak Bernam landfills that was ranging from 19 to 20, 66 to 70, 36 mg/L, respectively (Agamuthu, 2001). Sulfate concentration in the downstream groundwater of Seri Petaling Landfill was 3.57 mg/L (Ahmed & Sulaiman, 2001). In the downstream groundwater of a landfill in Greece, the average sulfate concentration at all sites was ranging from 4.2 to 112 mg/L (Fatta et al., 1999).

2.5 Groundwater and Hydrologic Cycle

Groundwater is a part of a hydrologic cycle, which is defined as the pathway of water as it moves in its various phases through atmosphere. This cycle includes both reservoirs in which water is stored and processes that transfer water between reservoirs. As indicated in Figure 2.1, runoff, groundwater flow, precipitation, evaporation, transpiration, and infiltration are among the processes involved in a hydrologic cycle. Precipitation occurs when water vapor in the atmosphere condenses on small particles. Evaporation is the transfer of water from the liquid to vapor state.

As shown in Figure 2.1, groundwater is formed when water that reaches earth's surface infiltrates rock and soil and reaches saturated zones. Faster infiltration rates are usually associated with loose, dry, sandy soils. Groundwater flows through subsurface and discharges to springs, lakes, rivers, and oceans. When groundwater flows into a river, the river is said to be effluent. Effluent rivers are common in humid regions where the water table is near the land surface. Effluent rivers can become influent during periods of flooding, when water levels in the rivers rise much faster than in groundwater (Hudak, 2000).

Precipitation accumulates on the land surface and may eventually flow over the land surface as runoff when the infiltration capacity of the soil is satisfied. This runoff can be in the form of sheet flow, in which no channels confine the water and it may eventually reaches gullies and river channels. The land area that can contribute to the runoff at any particular location is determined by the shape or topography of the region surrounding the location. The potential contributing area is called the watershed, the area within a watershed over which rainfall occurs is called the catchment area (Chin, 2000).



Note: Numbers indicate relative magnitudes of various fluxes

Figure 2.1: Schematic diagram of a hydrologic cycle (Chin, 2000)

2.6 Groundwater and Aquifer Properties

An aquifer is a rock unit that will yield water in a useable quantity to a well or spring. Groundwater occurs in aquifers under two different conditions. Where water only partly fills an aquifer, the upper surface of the saturated zone is free to rise and decline. The water in such aquifer is said to be unconfined, and the aquifers are referred to as unconfined or water table aquifers. Where water completely fills an aquifer that is overlain by a confining bed, the water is said to be confined. The properties that govern the capability of an aquifer to store, to transmit, and to yield groundwater are total porosity, effective porosity, hydraulic conductivity, intrinsic permeability, transmissivity, and specific yield. These parameters are defined in the following sections.

2.6.1 Hydraulic Conductivity

Hydraulic conductivity depends on the size and arrangement of the water-transmitting openings (pores and fractures) and on the dynamic chararacteristics of the fluid (water) such as viscosity, density, and the strength of the gravitational field. Hydraulic conductivity can also be expressed as (Weight & Sonderegger, 2001)

$$K = \frac{k_{ii} \rho \, g}{\mu} \tag{2.1}$$

where K, k_{ii}, ρ, and μ are the hydraulic conductivity, intrinsic permeability, groundwater density and viscosity, respectively. Hydraulic conductivity may also be different in different directions at any place in an aquifer. An isotropic aquifer is when the hydraulic conductivity is the same in all directions and an anisotropic aquifer is when the hydraulic conductivity was different in different directions. The aquifer is said to be homogeneous if the hydraulic conductivity is the same in any area. If the hydraulic conductivity differs from one part of the area to another, the aquifer is said to be heterogeneous. The ranges of hydraulic conductivity values for various earth materials are shown in Figure 2.2.

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