

Characterization of lake water–groundwater exchange at Lake L5, Universiti Teknologi PETRONAS, Malaysia

K. U. Orji, N. Sapari & K. W. Yusof

Department of Civil Engineering,

Universiti Teknologi PETRONAS, Malaysia

Abstract

Mining lakes are rarely used in Malaysia for raw water supply in water treatment despite their abundance. This is based on the general view that they are just mere retention ponds. However, there is growing acknowledgement that surface water features such as rivers and lakes can exchange water with underlying aquifers and this water movement can have significant implications on water quantity. This study examined the interaction between surface water (mining lake water) and groundwater (aquifer) using Lake L5 at the Universiti Teknologi PETRONAS, Perak, Malaysia, as a case study. Seepage meters and mini piezometers were used to evaluate the seepage flux rates, direction, and magnitude of water flow between the aquifer and the lake water. The seepage flux rates were found to be in the range of $3.45 \text{ Lm}^{-2}\text{day}^{-1}$ to $11.08 \text{ Lm}^{-2}\text{day}^{-1}$ and the Vertical Hydraulic Gradients (VHG) of the mini piezometers was within the range of 0.022 to 0.196. The results from these methods were positive, correlated and confirmed that groundwater was being discharge into the lake water; and that the farther the monitoring equipment from the shoreline, the lesser the groundwater discharge. Further research is required to be carried out for a longer period, under different hydrological conditions and time of the year, and at several locations.

Keywords: mining lake, groundwater, interaction, seepage meters, mini piezometers.



1 Introduction

Rivers provide main water source for 97% of drinking water supply for domestic, industrial and agriculture in Malaysia [1]. Mining lakes are rarely used for raw water supply for water treatment despite their abundance in the country [2, 3]. This is based on the general view about mining lakes water in Malaysia. Mining lakes are viewed as retention ponds which can be dried up when used for water supply. However, there is growing acknowledgement that surface water features such as rivers and lakes can exchange water with underlying aquifers and this water movement can have significant implications on water quantity and quality [4]. The degree and nature of connectivity between lakes and groundwater resources influence the extraction, potential, contamination, and flow characteristics. The interaction between surface water (lakes) and groundwater is important because it forms the basic framework in the evaluation of water budgets for water supply and also groundwater transports of chemical solutes to the surface water bodies.

These exchange between groundwater and lakes can occur in three different dimensions vis-à-vis: some lakes recharge groundwater throughout the entire lake beds; others are being recharged by the groundwater throughout the beds; while some lakes receive groundwater inflows in some part of their beds and recharge groundwater through the other parts [5, 6].

There are different methods of evaluating fluxes between a lake and aquifer. They include seepage flux (using seepage meter), heat tracer methods, mini piezometer, monitoring wells, pumping tests, hydraulic conductivity, isotopes and chemical tracers, etc. This study used seepage meters and mini piezometers for its evaluations. The reason behind this choice was that these instruments are inexpensive and have direct measurement of seepage flux at the interface between lake and aquifer. The performance of a seepage meter and mini piezometer has been tested in several studies [4, 5, 7–12]. This study sought to evaluate in details the interaction between groundwater and UTP Lake L5 (4°23'08.46"N and 100°58'45.36"E). Its specific objectives were to (i) determine the locations, rates and directions of groundwater seepage using the above methods; and (ii) to compare the results of these methods.

2 Materials and methods

2.1 Description of lake L5

There are eight lakes located inside the University Teknologi PETRONAS (UTP) campus in Seri Iskandar, Perak, Malaysia. They are labeled as L1, L2, L3, L4, L5, L6, L7, and L8 (Figure 1). L2, L3, L4, and L8 are the upstream lakes of Lake L7, which in turns flows into Lake L6. L5 has a surface area of 68,739.52 m² (6.874 ha). It is located near the security gate of the university. The lake is part of the UTP chain of lakes which flows into Lake L6. The overall water that flows into Lake L6 is finally discharged to other lakes outside the campus through a weir.



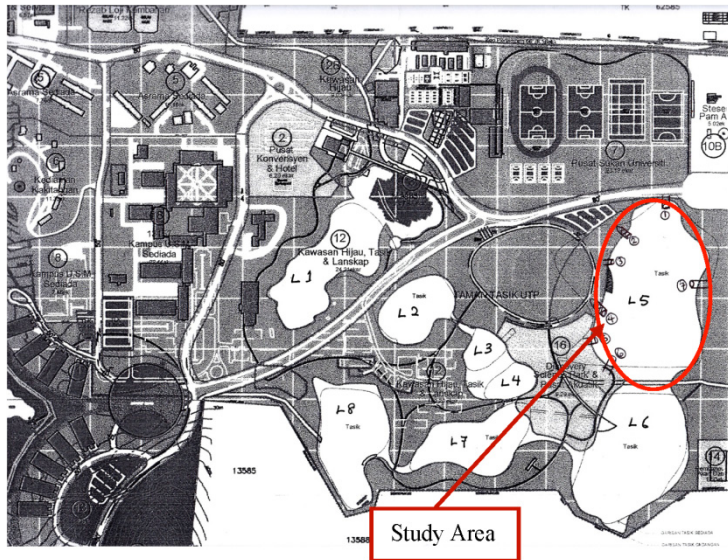


Figure 1: Map of the Universiti Teknologi PETRONAS, UTP ($4^{\circ}23'08.46''\text{N}$ and $100^{\circ}58'45.36''\text{E}$) showing various mining lakes (source: Maintenance Dept., UTP).

2.2 Methods

Two experiments were conducted within the study area. They include measuring the groundwater discharge using seepage meters and mini piezometers.

2.2.1 Seepage meter

The quantity of groundwater seepage into the lake was determined using seepage meters. They were designed, constructed and installed at four different locations (T_1 to T_4) on the lake bed (Figure 2(a) and (c)). Seepage flux of the lake's groundwater was then measured by enclosing a particular area of the lake bottom with a cylinder vented to a plastic bag [4, 9, 10 and 13]. The meter was constructed using a 200 L steel drum (diameter = 0.57 m) that was cut into halves. Four flanges were welded at the top of the closed end of the drum and each flange was tied to a 6 kg of rock. This was done to ensure that during installation, the drum moved down to the bottom of the lake without interference. The drum's bung hole ($\frac{1}{2}$ inch) in the closed end was then fitted with a watertight connector that was connected to a 10 L polyethylene bag through a 2 meter hose (diameter = 15 mm) and was tightened using hose clamps and rubber bands. Prior to the installation of the seepage meter, 1 L of water was introduced into the polyethylene bag and tied to the hose. This was recorded as the initial volume of water in the bag. The seepage meter equalized with the groundwater for twenty four hours before data collection. The collected water in the bag over the twenty four hours represented the amount of groundwater

seepage which could enter or exit the lake through the lake's bottom. The seepage flux was calculated as follows:

$$Q = \frac{V_f - V_o}{tA} \quad (1)$$

Q = Seepage flux or seepage volume per area ($\text{lm}^{-2} \text{ day}^{-1}$)

V_f = Final volume of water in the bag (l)

V_o = Initial volume of water in the bag (l)

t = Time elapsed between when the bag was connected and disconnected (day)

A = Surface area of the chamber (0.255 m^2).

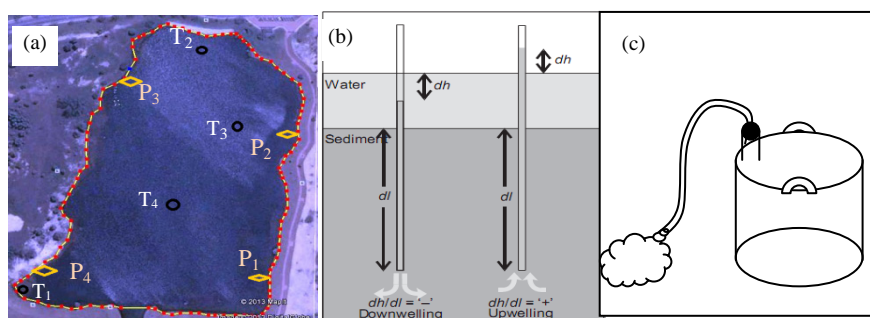


Figure 2: (a) UTP lake 15 showing mini piezometer and seepage meter stations (b) vertical hydraulic gradient in a downwelling and upwelling region of the lakebed (adapted from Rautio and Korkka-Niem [5]) and (c) seepage meter.

The values of seepage flux were multiplied by a correction factor of 1.05, which was introduced by Belanger and Montgomery [14], to take care of all the possible errors due to flow resistance to the drum and the plastic bag during the measurements.

2.2.2 Mini piezometers

A mini piezometer is a device used to measure the direction of water flow between surface water body such as a lake and aquifer (Figure 2(b)). It estimates the characterization of the magnitude and direction of vertical hydraulic gradient (VHG) [15, 16]. The Vertical Hydraulic Gradient (VHG) values at certain depths in a single point between a lake and groundwater were computed using the formula:

$$VHG = \frac{dh}{dl} \quad VHG = \frac{dh}{dl} \quad (2)$$

dh = hydraulic head difference between the mini piezometer and lake stage (cm);

dl = vertical distance between the lake bed and the midpoint of the perforated screen mini piezometer (cm) [5, 17].

Four piezometer stations (P_1 to P_4) were installed at different locations of the lake (Figure 2(a)). The PVC piezometer has an outer diameter of 2 cm. There were 12 mini piezometers used for the study and had perforated screens of various lengths. They were installed by a hand auger, and drilling of 10 cm wide borehole. The auger material was used to backfill the borehole after installation. The lake water levels (h_2) were measured with a meter rule, midpoints of the perforated areas marked, and groundwater levels obtained using the water level meter (YAMAYO Million Rope Water Level Measure – 50 m). A positive value of VHG indicates groundwater recharges the lake while a negative value shows the opposite. Three mini piezometers were installed perpendicular to the shoreline at each station so as to measure the head differences and to characterize the magnitude and directions of the VHG.

3 Results and discussions

3.1 Seepage meter

The various volumes of water obtained using seepage meters in these four locations are shown in Table 1.

Table 1: Summary of seepage meter data obtained at UTP lake L5, UTP.

Location	Lake's Depth (m)	Date	n	I (m)	Initial Volume (L)	Final Volume (L)	Change in Volume (L)	Seepage Flux ($\text{Lm}^{-2}\text{day}^{-1}$)
T1	2.6	12/11/13	1.05	3.80	1.0	3.69	2.69	11.08
T2	5.47	13/11/13	1.05	10.54	1.0	2.20	1.20	4.94
T3	7.8	14/11/13	1.05	30.06	1.0	2.10	1.10	4.53
T4	10.03	15/11/13	1.05	98.12	1.0	1.84	0.84	3.45

I = distance from shoreline (m), n = correction factor.

The seepage flux rates ranged from $3.45 \text{ Lm}^{-2}\text{day}^{-1}$ to $11.08 \text{ Lm}^{-2}\text{day}^{-1}$. The highest seepage flux was obtained near the shoreline. The study revealed that the seepage fluxes decreased with increasing distance from the shoreline. It also indicated that all the four locations experienced recharge of groundwater into the lake (Figure 3(a)). Rautio and Korkka-Niem [5] and McCann *et al.* [17] obtained similar results.

3.2 Mini piezometer

The measured hydraulic head differences (dh) within the four stations showed upward flow of groundwater (Table 2 and Figure 3(b)–(e)). The study revealed that all the results obtained for the vertical hydraulic gradients (VHG) were positive. It was also deduced from the study that the greater the installation depth

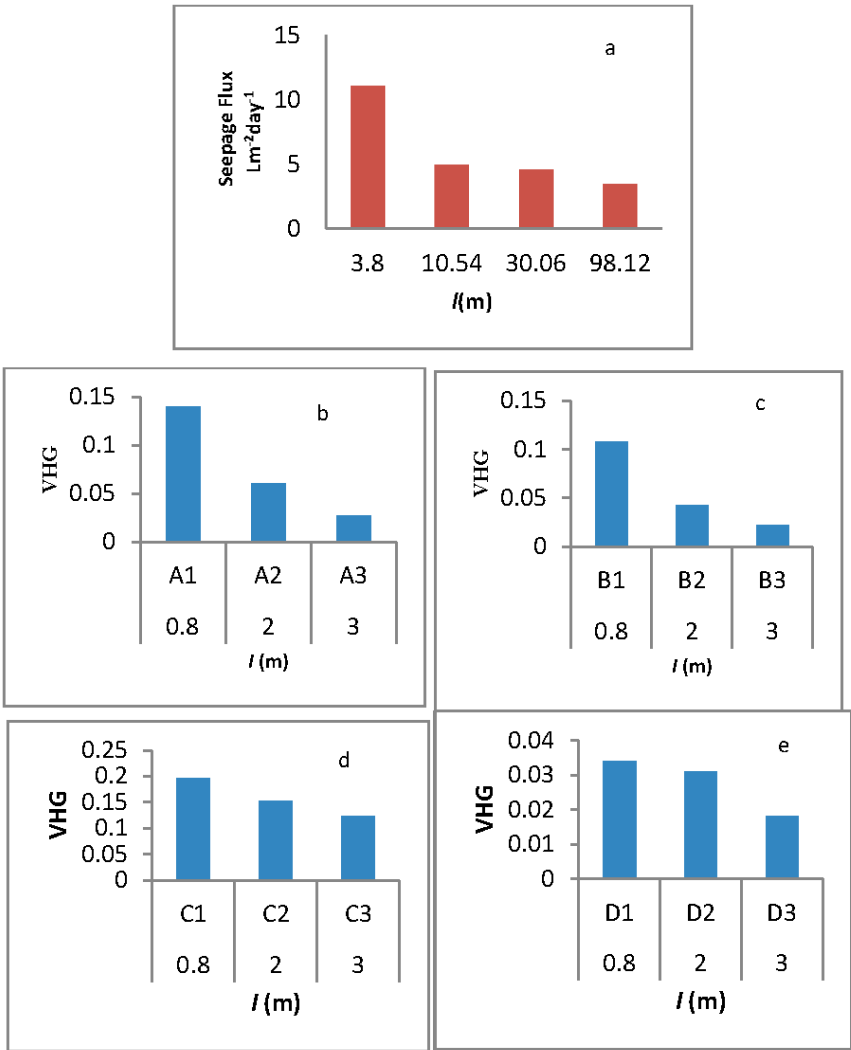


Figure 3: Relationship between groundwater recharge and distance from shoreline at Lake L5, UTP (a) with seepage meter (b)–(e) with mini piezometers [l = distance from shoreline].

of the mini piezometer, the higher the level of groundwater in the pipe (h_l). The results from the study were similar to the ones obtained by Rautio and Korkka-Niem [5] and Rosenberry and LaBaugh [16] in which their hydraulic head differences (dh) did not exceed 30 cm. It also confirmed what was obtained using the seepage meter in relation to shoreline distance and amount of groundwater recharge.

Table 2: Mini piezometer data collected at Lake L5, UTP.

Station	Locations	$I(m)$	$dl(cm)$	$h_1(cm)$	$h_2(cm)$	$dh(cm)$	VHG
1	A1	0.8	50	20	13	7	0.140
	A2	2	100	23	17	6	0.060
	A3	3	150	65	61	4	0.027
2	B1	0.8	120	27	14	13	0.108
	B2	2	120	35.2	30	5.2	0.043
	B3	3	120	42.6	40	3	0.022
3	C1	0.8	168	109	76	33	0.196
	C2	2	170	110	84	26	0.153
	C3	3	189.4	114.5	91	23.5	0.124
4	D1	0.8	103	37.5	34	3.5	0.034
	D2	2	146	52.5	48	4.5	0.031
	D3	3	136	53.5	51	2.5	0.018

I = distance from shoreline (m), dl = the vertical distance between the lakebed and the midpoint of the perforated mini piezometer (cm), h_1 = the level of groundwater in the mini piezometer, h_2 = the lake water level, dh = head difference (cm), VHG = Vertical Hydraulic Gradient.

4 Conclusions

The overall objective of this study was to examine the groundwater–lake water interactions. The goal was specifically to investigate the directions and rates of groundwater seepage with mini piezometers and seepage meters. This was actualized from the conducted experiments. The above results indicated that water was being recharged from groundwater to the lake as at the time the experiments were conducted. The average seepage flux of the lake was $6 \text{ Lm}^{-2} \text{ day}^{-1}$ and VHG was 0.080. However, directions and flow rates between the lake water and groundwater could be dynamic and change over time and space due to response to seasonal weather conditions and water flow. In order to fully ascertain the groundwater – surface water interactions of Lake L5, it is recommended that a longer period of study be conducted under different hydrological conditions and time of the year and at several locations.

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