Evaluation of Groundwater Interaction with Lake L5, Universiti Teknologi Petronas, Malaysia, using Seepage Meter and Mini-Piezometer

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A b s t r a c t

Malaysia has many abandoned mining lakes. These lakes are rarely used 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 interact with underlying aquifers and this water movement can have significant implications on water quantity. This research investigated the interaction between mining lake water and groundwater using Lake L5 at the Universiti Teknologi PETRONAS, Perak, Malaysia, as a case study. Seepage meters and Mini-Piezometers were used to estimate the seepage flux rates, direction, and magnitude of water flow between the aquifer and the lake water within the months of August and November 2013. The seepage flux rates ranged from 2.47 Lm⁻²day⁻¹ to 7.33 Lm⁻²day⁻¹ for August and 3.45 Lm⁻²day⁻¹ to 11.08 Lm⁻²day⁻¹ for November respectively. The results from these methods were all positive, 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. More study is required to be carried out for a longer period, under different hydrological conditions and time of the year, and at several locations.

1. Introduction

Surface water such as river is the major source of water and accounts for 97% of drinking water supply for domestic, industrial and agriculture in Malaysia [1]. Abandoned tin mining lakes represent significant water body, particularly in the States of Perak, Selangor, and Negeri Sembilan. These mining pools are seldom used as sources of water for the treatment of public water supply despite their abundance. They have basically been used for irrigation, recreational activities, aquaculture activities and retention ponds. Perak State has about 63% of Malaysian ex-tin mining pools [2 & 3]. The reason is based on the general view that mining lakes are more of retention ponds which can easily be dried up when used for water supply. However, research has shown that lakes can exchange water with underlying aquifers and this water movement can have significant implications on water quantity and quality [4, 5, & 6]. The degree and nature of connectivity between lakes and groundwater resources influence the extraction, potential, contamination, and flow characteristics. The interaction between lakes and groundwater forms the basic framework in the estimation of water budgets for water supply and also groundwater transports of chemical solutes to the surface water bodies [4].

These exchange between groundwater and lakes can take place in three dimensions: 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 measures of evaluating fluxes between a lake and aquifer. These include Mini-Piezometer, seepage flux, heat tracer methods, monitoring wells, pumping tests, hydraulic conductivity, isotopes and chemical tracers, and host of others. This research used Seepage meters and Mini-piezometers for its findings. These instruments are inexpensive and have direct measurement of seepage flux at the interface between lake and groundwater. The performance of Seepage Meter and Mini-Piezometer has been tested in several studies [4, 5, & 7 - 12]. This research sought to estimate in details the interaction between aquifer and Lake L5 (4°23′08.46″N & 100°58′45.36″E). Its objectives were to (i) determine the locations, rates and directions of groundwater seepage; and (ii) to compare the results of these methods.

2. Materials and Methods

2.1 Description of Lake L5

The eight lakes found on the campus of the Universiti Teknologi PETRONAS (UTP) in Seri Iskandar, Perak, Malaysia are labeled as L1, L2, L3, L4, L5, L6, L7, and L8. These lakes can be identified in Figure 1. Lake L2, L3, L4, and L8 are the upstream lakes of Lake L7, which in turns flows into Lake L6. UTP Lake L5 has a total rough surface area of 68,739.52 m$^2$ (6.874 ha). It is located near the Security gate of the University. The lake is also bounded on the North by the security gate, road, and mini sports complex; in the East by jogging tracks, small landscaped field with grasses and few trees, an impervious road that leads to the PETRONAS filling station, and car park; it is also bounded on the South by Lake L6; and on the West by a large landscaped field with grasses and trees. 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. Despite the fact that a formal wildlife survey has not been carried out, it can be deduced that the lake supports a diverse wildlife community. During the study period, wildlife observed included alligators and several species of fish.

Fig. 1: Map of the Universiti Teknologi PETRONAS, UTP (4°23′08.46″N & 100°58′45.36″E) showing various Mining Lakes (Source: Maintenance Dept., UTP)
2.2 Methods

Two experiments were conducted within the study area in August and November 2013. The experiments include measuring the groundwater discharge using seepage meters and mini-piezometers. These two months fall in dry and rainy seasons in Perak, Malaysia.

2.2.1 Groundwater Seepage Meter

The quantity of groundwater seepage into the lake and vice versa was estimated using seepage meters. These meters were designed, constructed and installed at four different locations (T1 to T4) on the lake bed (Figure 2a & 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, & 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 6kg 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 whose diameter was 0.5 inch was fitted with a watertight connector that was connected to a 10L 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, 1L 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:

\[ Q = \frac{V_f - V_i}{At} \]

Where,

Q = Seepage flux or seepage volume per area (l m^-2 day^-1)
V_f = Final Volume of water in the bag (l)
V_i = 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).

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

Mini-Piezometer is used to measure the direction of water flow between surface water body such as a lake, stream or river and aquifer (Figure 2b). It determines 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:

\[ VHG = \frac{dh}{dl} \]

Where,
\[ dh = \text{hydraulic head difference between the mini-piezometer and lake stage (cm)} \]
\[ dl = \text{vertical distance between the lake bed and the midpoint of the perforated screen mini-piezometer (cm)} \]

Four piezometer stations (\( P_1 \) to \( P_4 \)) were installed at different locations of the lake (Figure 2a). 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. The seepage flux rates ranged from 2.47 Lm\(^{-2}\)day\(^{-1}\) to 7.33 Lm\(^{-2}\)day\(^{-1}\) for August and 3.45 Lm\(^{-2}\)day\(^{-1}\) to 11.08 Lm\(^{-2}\)day\(^{-1}\) for November. The highest seepage flux for the seasons was obtained near the shoreline. The research indicated that the seepage fluxes decreased with increasing distance from the shoreline. It also revealed that all the four locations for the two seasons experienced recharge of groundwater into the lake (Figure 3a). Anne & Kirsti, 2011 and Kelvin et al, 1997 obtained similar results [5 &17].
Table 1: Summary of Seepage Meter Data Obtained at UTP Lake L5 in August and November 2013

<table>
<thead>
<tr>
<th>Month (2013)</th>
<th>Location</th>
<th>Lake’s Depth (m)</th>
<th>Date</th>
<th>$I$ (m)</th>
<th>$n$</th>
<th>Initial Volume (L)</th>
<th>Final Volume (L)</th>
<th>Change in Volume (L)</th>
<th>Seepage Flux (L·m$^{-2}$·day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>August</td>
<td>T1</td>
<td>1.85</td>
<td>28/8/13</td>
<td>1.05</td>
<td>3.65</td>
<td>1.0</td>
<td>2.78</td>
<td>1.78</td>
<td>7.33</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>5.0</td>
<td>29/8/13</td>
<td>1.05</td>
<td>11.0</td>
<td>1.0</td>
<td>2.00</td>
<td>1.00</td>
<td>4.12</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>7.19</td>
<td>30/8/13</td>
<td>1.05</td>
<td>28.10</td>
<td>1.0</td>
<td>1.65</td>
<td>0.65</td>
<td>2.68</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>8.3</td>
<td>31/8/13</td>
<td>1.05</td>
<td>99.00</td>
<td>1.0</td>
<td>1.60</td>
<td>0.60</td>
<td>2.47</td>
</tr>
<tr>
<td>November</td>
<td>T1</td>
<td>2.6</td>
<td>12/11/13</td>
<td>1.05</td>
<td>3.80</td>
<td>1.0</td>
<td>3.69</td>
<td>2.69</td>
<td>11.08</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>5.47</td>
<td>13/11/13</td>
<td>1.05</td>
<td>10.54</td>
<td>1.0</td>
<td>2.20</td>
<td>1.20</td>
<td>4.94</td>
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<td></td>
<td>T3</td>
<td>7.8</td>
<td>14/11/13</td>
<td>1.05</td>
<td>30.06</td>
<td>1.0</td>
<td>2.10</td>
<td>1.10</td>
<td>4.53</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>10.03</td>
<td>15/11/13</td>
<td>1.05</td>
<td>98.12</td>
<td>1.0</td>
<td>1.84</td>
<td>0.84</td>
<td>3.45</td>
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</table>

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

Fig. 3a: Relationship between groundwater recharge and distance from shoreline at Lake L5, UTP with seepage meter

3.2 Mini Piezometer

It can be shown from Table 2 and Figure 3b-e that there were upward flows of groundwater in the experimental hydraulic head differences ($dh$) within the four stations. The results obtained for the vertical hydraulic gradients (VHG) were all positive for August and November. The results also showed that more water was recharged from groundwater into the lake in November (rainy season) than August (dry season). This could be as result of the increase in groundwater table due to precipitation. It was also deduced from the study that the greater the installation depth of the mini-piezometer, the higher the level of groundwater in the pipe ($h_i$). The results from the study were
similar to the ones obtained by Anne and Kirsti, 2011 and Rosenberry and LaBaugh, 2008 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, for August and November, 2013

<table>
<thead>
<tr>
<th>Month</th>
<th>Station</th>
<th>Locations</th>
<th>$I$ (m)</th>
<th>$dl$ (cm)</th>
<th>$h_1$ (cm)</th>
<th>$h_2$ (cm)</th>
<th>$dh$ (cm)</th>
<th>VHG</th>
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<tr>
<td>August 2013</td>
<td>A1</td>
<td>0.8</td>
<td>52</td>
<td>16</td>
<td>11</td>
<td>5</td>
<td>0.096</td>
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<tr>
<td></td>
<td>A2</td>
<td>2</td>
<td>97</td>
<td>19</td>
<td>14</td>
<td>5</td>
<td>0.052</td>
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<tr>
<td></td>
<td>A3</td>
<td>3</td>
<td>150</td>
<td>50</td>
<td>47</td>
<td>3</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>0.8</td>
<td>120</td>
<td>23</td>
<td>12</td>
<td>11</td>
<td>0.092</td>
<td></td>
</tr>
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<td></td>
<td>B2</td>
<td>2</td>
<td>120</td>
<td>33</td>
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<td>4.3</td>
<td>0.036</td>
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<td>B3</td>
<td>3</td>
<td>120</td>
<td>38</td>
<td>35.8</td>
<td>2.2</td>
<td>0.018</td>
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<td>0.8</td>
<td>160</td>
<td>104.1</td>
<td>73.6</td>
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<td>0.190</td>
<td></td>
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<tr>
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<td>C2</td>
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<td>172</td>
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<td>82</td>
<td>23</td>
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<tr>
<td></td>
<td>C3</td>
<td>3</td>
<td>185</td>
<td>106</td>
<td>86.3</td>
<td>19.7</td>
<td>0.107</td>
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<tr>
<td></td>
<td>D1</td>
<td>0.8</td>
<td>100</td>
<td>33.3</td>
<td>30.5</td>
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<tr>
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<td>D2</td>
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<tr>
<td></td>
<td>D3</td>
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<td>135</td>
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<td>2.1</td>
<td>0.016</td>
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<td>November 2013</td>
<td>A1</td>
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<td>50</td>
<td>20</td>
<td>13</td>
<td>7</td>
<td>0.140</td>
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<td>A2</td>
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<td>6</td>
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<td>B3</td>
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<td>109</td>
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<td>C2</td>
<td>2</td>
<td>170</td>
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<td>84</td>
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<td>3.5</td>
<td>0.034</td>
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<td>48</td>
<td>4.5</td>
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<td>136</td>
<td>53.5</td>
<td>51</td>
<td>2.5</td>
<td>0.018</td>
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</table>

$I$ = 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
Fig. 3b-e: Relationship between groundwater recharge and distance from shoreline at Lake L5, UTP with mini-piezometers [l = Distance from shoreline]

Conclusion
This research was to examine the groundwater–lake water exchange. The goal was characteristically to investigate the directions and rates of groundwater seepage with mini-piezometers and seepage meters. This was realized from the conducted experiments. The results above showed that water was being recharged from groundwater to the lake. The average seepage flux of the lake was 4.15 Lm$^{-2}$day$^{-1}$ and VHG was 0.080 for August; and 6 Lm$^{-2}$day$^{-1}$ and VHG was 0.080 for November. This showed that later water recharge was higher in rainy season than dry season due to precipitation. 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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References


