Perched Water Table Mounding Between Subsoil Drains in Sand

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ACKNOWLEDGEMENTS

The experimental data on which this paper is based were collected by JDA Consultants Hydrologists on behalf of Peet Oakford Land Syndicate Ltd.

StormTech Pty Ltd provided the StormTech arched polypropylene chambers used in the Trial.

The opinions expressed are those of JDA and not necessarily those of Peet Oakford Land Syndicate Ltd or StormTech Pty Ltd.
1. INTRODUCTION

Subsoil drainage is used throughout the world to control shallow groundwater levels to facilitate land use in both agricultural and urban development. The term subsoil implies that a buried pipe is used as opposed to an open drain, usually where land values are high.

The primary mechanism by which subsoil drainage functions is the provision of an outlet from a slotted pipe system such that groundwater can flow by gravity, according to Darcy’s law, towards the pipe thus lowering groundwater levels.

Subsoil drainage is usually constructed in parallel or sub-parallel lines, so that the water table mounds between the parallel drainage lines.

Critical parameters determining whether a subsoil drainage system operates as intended are: the soil permeability, the volume of water to be drained in unit time and drain spacing.

On the Swan Coastal Plain subsoil drainage has been used in urban developments where the water table has been shallow for decades, generally with success owing to the permeable sandy soils and the relatively low rainfall in the South West of Western Australia.

This paper describes a subsoil drainage experimental site on relatively impermeable Guildford Formation soils in the City of Armadale, instrumented to monitor water table mounding between a set of parallel subsoil drains in imported sand-fill in 2009 and 2010.

The paper describes the data collected, together with application of a suitable model to represent the relevant components of water flux, and an application of that model to assist the design the subsoil drainage systems for the Perth metropolitan area.
2. OBJECTIVES OF PAPER

i. To describe a field trial of perched water table mounding control using StormTech units in sand-fill in 2009 and 2010 (Chapter 3).

ii. To describe the perched water table that develops in imported sand-fill above Guildford Formation clay (Chapter 4).

iii. To present data on perched water table mounding height from the trial (Chapter 5).

iv. To calibrate a groundwater model to the perched water table data (Chapter 6).

v. To apply the model to estimate perched water table mounding height in a wet year post-development (Chapter 7).
3. FIELD TRIAL

The trial site is located in the City of Armadale approximately 30km south-east of the Perth CBD, Western Australia. The trial has a total area of 8000m$^2$, see Figures 1 and 2.

Figure 1: Field Site Location
The surface geology is Guildford Formation which consists predominantly of grey and brown clays and silts that were deposited as coalescing alluvial fans in a piedmont setting at the foot of the Darling Scarp (Gozzard, 2005), as shown in Figure 3.
Daily rainfall data was sourced from the nearest BOM’s gauging station in Anketell (Site No. 009258). StormTech Pty Ltd provided 2 x 100m long sections (west and east) of arched polypropylene chambers which were laid in a gravel envelope with geotextile fabric, see Figure 4.
The chambers have an external width of 864mm and height of 406mm (StormTech SC-310 chambers).

Figure 4 shows the 2 north-south lines of chambers and the location of monitoring bores.

The units were installed 80m apart, both aligned north-south to discharge into a Park Avenue at the northern end.

The inverts of the western upstream and downstream ends are 26.0 mAHD and 25.9 mAHD respectively. Corresponding inverts for the eastern drain are 25.9 mAHD and 25.8 mAHD. The base of the sand-fill is between 25.8 mAHD and 25.9 mAHD. The drains were laid at the interface between the sand-fill and the underlying Guildford Formation.

The sand-fill ground level ranges between a minimum of 27.5 mAHD and a maximum of 28.0 mAHD.

The StormTech units operated as subsoil drains, flowing part full during periods of water table rise above inverts.

Water table monitoring bores (deep and shallow) were installed between the drains, see Fig. 5.
The installation of the trial site occurred in mid-2009. During winter 2009 the Park Avenue was inundated and prevented the free discharge of the StormTech units, rendering the winter 2009 data unusable.

Prior to winter 2010 a temporary outlet for the Park Avenue was excavated on the northern side which ensured that winter 2010 water levels in Park Avenue drain did not obstruct the outflow from StormTech units.
4. DEVELOPMENT OF PERCHED WATER TABLE

Water level in monitoring bores was measured manually using an electrical dip-probe on a fortnightly basis and water level dataloggers were installed in bore P50S (50m south of Park Avenue at the centreline between parallel drains) and P50/38W (50m south of the Park Avenue, 38m west of the centreline). Water level data measured at the centreline of the parallel drains is shown in Figure 6.

Figure 6 shows at the start of 2010 there was no perched water table within the sand-fill but that as the year progressed, starting with the 22 March hail and rain, a saturated zone (perched water table) did develop within the imported sand-fill.
In comparison Figure 7 shows water level data for a control bore C50D slotted in the Guildford Formation measuring the regional water table.

It can be seen that these water levels are several metres below the perched water table in the sand-fill.

Figure 8 shows contours of the perched and regional water table on 15 July 2010 when the perched
water table was at its highest. Figure 9 shows the regional groundwater level to be approximately 22 mAHD, compared with the perched water table at approximately 26.5 mAHD.

Figure 9 shows contours on the date of maximum perched water table mounding on 15 July 2010.
Figure 6 shows that the perched water table mounding height increased during winter 2010 to a maximum of 0.68m on 15 July 2010.

Figure 6 shows that the mounding at the centreline between the parallel drains occurred progressively during the period March to July 2010 with a rise following rainfall and then a slow recession until the next rainfall event.

This is thought to be the first such set of data collected in Perth and provides insights into how a perched water table develops in imported sand-fill above Guildford Formation.

It is of interest to note that the water table mound at the centreline between parallel drains increases gradually during the winter period following successive rain storms, receding in between.

This is in contrast to the commonly held belief that the mounding between subsoil drains occurs due to a heavy rainfall event such as 24hr 5yr storm event. Figure 6 clearly shows that it is not an individual storm event which gives rise to the maximum mounding height, but rather the cumulative effect of rainfall over a full winter period.
6. GROUNDWATER MODEL OF PERCHED WATER TABLE

The MODFLOW saturated groundwater flow model was established over the 8000m$^2$ trial area.

Boundary conditions were set as fixed head along the StormTech drain lines and along Park Avenue and no flow boundary between the southern ends of the StormTech units.

MODFLOW assumes that rainfall recharge occurs at the same time as rainfall with a certain percentage rainfall recharge. That is, MODFLOW does not have an unsaturated model for the movement of water above the water table.

The important parameters with the MODFLOW model are the porosity and hydraulic conductivity.

Porosity is defined as the ratio between the volume of the voids ($V_{\text{void}}$) and the total volume of the soil ($V_{\text{Tot}}$).

\[ n = \frac{V_{\text{void}}}{V_{\text{Tot}}} \quad [0<n<1]. \]

Typically for sand, [n=0.15 to 0.25].

Hydraulic conductivity describes the ease with which water can move through soil and defined as the rate of flow under unit hydraulic gradient.

For simplification the groundwater flow equation can be written as follows:

\[ Q \ [\text{m}^3/\text{t}] = K \ [\text{m/s}] \ [i] \ A \ [\text{m}^2] \]  

[Eqn. 1]

Equation 1 is known as Darcy’s Law.

In Eqn. 1, Q is a volumetric flow-rate, K is the hydraulic conductivity, i is hydraulic gradient and A is the area of the cross-section.

The relationship between porosity and hydraulic conductivity is governed by the change of water flow direction in the three directions (x, y, z) which MODFLOW computes.

Also of importance is the specific yield which relates to the volumetric fraction of the aquifer volume that can be yielded when all the water drains out under gravity. For sandy soils a specific yield ranges between 0.1 to 0.2 (Davidson, 1995).

The model was calibrated and adopted parameters are presented in Table 1.
TABLE 1: MODFLOW CALIBRATION PARAMETERS

<table>
<thead>
<tr>
<th>Recharge</th>
<th>Type</th>
<th>Source</th>
<th>Rainfall, Daily Data [mm/unit time]</th>
<th>Rate</th>
<th>BoM</th>
<th>80%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sy</td>
<td>Value</td>
<td></td>
<td>0.16 (16%) [dimensionless]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kv,h</td>
<td>Value</td>
<td></td>
<td>12m/day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation from water</td>
<td>Type</td>
<td>Source</td>
<td>Function of depth [mm/unit time]</td>
<td>Rate</td>
<td>Luke et al, 1988</td>
<td>0%</td>
</tr>
</tbody>
</table>

Specific yield is within the range proposed by Davidson, (1995).

A hydraulic conductivity of 12 m/day is generally accepted for a sand soil.

In terms of time, MODFLOW runs the model on a one day time step (i.e. Δt), for a total of 245 time-steps from 1 March to 31 October.

The rainfall recharge rate was set to 80% of daily rainfall due to the bare nature of the sand-fill for which there is no interception loss.

Figure 6 shows that with the adopted parameters, the MODFLOW model represents very well the recorded water levels at P50S at the centreline between the parallel subsoil drains.
Figure 10 shows a MODFLOW calibration plot showing generally calibration within 0.1m of the mounding. The largest difference is indicated on Figure 10 for 22 March 2010 which has an error of approximately 0.3m due to the rapid rise of the perched water table and a one day time-step used in the model.
7. PERCHED WATER TABLE MOUNDING POST-DEVELOPMENT

The calibrated groundwater model MODFLOW has been applied to a post-development land use scenario with a lower rainfall recharge rate of 40% and applied to the wettest year at the Anketell rainfall station since 2002, namely 2008 with 776 mm recorded between 1 March and 31 October.

Figure 12 shows the MODFLOW estimation of perched water table mounding centreline between the parallel drains of 0.52 m on 2 August 2008.

Despite a different rainfall pattern from the experimental data of 2010 the development of the perched water table similarly progresses through a series of rainfall events and subsequent recessions to a maximum in July/August of the year.
Please note:
- Maximum mounding occurred on stress period #134 which corresponds to 12/07/2010
- Sand-fill layer surface (i.e. 27.5 mAHDI circa) not displayed for enhanced mounding stratification

Figure 11: 3D MODFLOW Output of Pre-Dev Maximum Mounding 12/07/2010

Please note:
- Maximum mounding occurred on stress period #155 which corresponds to 2/08/2008
- Sand-fill layer surface (i.e. 27.5 mAHDI circa) not displayed for enhanced mounding stratification

Figure 13: 3D MODFLOW Output for Post-Dev Maximum Mounding: Wet Year
8. CONCLUSIONS

The trial described in this report presents the first known set of data on the development of a perched water table in imported sand-fill Guildford Formation in Perth.

During the experimental period of winter 2010 the maximum perched water table mounding at centreline between parallel subsoil drains (StormTech units) spaced 80m apart was 0.68m with bare sand scenario pre-development.

A groundwater model (MODFLOW) was calibrated to the data with realistic values of soil parameters.

The MODFLOW model has been used to estimate likely post-development perched water table mounding height in a wet year (2008) with more a realistic post-development rainfall recharge rate of 40%. The maximum mounding for this scenario was 0.52m.

There is close agreement between maximum perched water table mounding height in 2010 as measured during the trial on bare sand compared with the post-development scenario in a wetter year.

In particular, the higher recharge rate of rainfall applied for bare soil in 2010 (namely 80%) compared with a relatively lower rainfall recharge rate assumed post-development (namely 40%) has resulted in similar perched water table mounding of approximately 0.5 to 0.6 m.

It is concluded that this set of data and the calibrated groundwater model are the best tool for estimating perched water table mounding heights in sand fill on Guildford Formation.
9. REFERENCES

Bureau of Meteorology, Average Pan Evaporation data, 2010.

Bureau of Meteorology, Daily Rainfall Data at Anketell Rain Gauging Station, 2010.


Luke et al. (1988) Evaporation Data for Western Australia