Perched Water Table Mounding Between Subsoil Drains in Sand Fill for Urban Development

Gregorio Serafini
Engineering Hydrologist, JDA Consultant Hydrologists, Subiaco, Western Australia
E-mail: **gregorio@jdahydro.com.au**

Dr Jim Davies
Principal Hydrologist, JDA Consultant Hydrologists, Subiaco, Western Australia
E-mail: **jim@jdahydro.com.au**

Alex Rogers
Senior Engineering Hydrologist, JDA Consultant Hydrologists, Subiaco, Western Australia
E-mail: **alex@jdahydro.com.au**

Abstract

In Perth, capital of Western Australia, urban development is increasingly being proposed over areas with high groundwater table. Sand fill is imported to ensure adequate clearance of finished roads and lots above groundwater. Until recently, the land development industry has largely accepted this practice. However, this is now being reviewed due to sand supply shortage and consequent cost escalation. The paper describes a groundwater monitoring program in the City of Armadale during winter 2010 that provided a set of data on which a MODFLOW model has been calibrated.

1. INTRODUCTION

Subsoil drainage is used throughout the world to control shallow groundwater levels to facilitate land use in both agricultural and urban development areas. 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, drain spacing and outlet condition.

On the Swan Coastal Plain subsoil drainage has been used for decades in urban developments where the water table has been shallow, 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 the 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 in the design of subsoil drainage systems on the Swan Coastal Plain.

2. 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 8,000 m^2, see Figure 1. 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).

Daily rainfall data was sourced from the nearest Bureau of Meteorology (BoM) rainfall gauging station in Anketell (Site No. 009258).

StormTech Pty Ltd provided 2 x 100 m long sections (west and east) of arched polypropylene chambers which were laid in a gravel envelope with geotextile fabric, see Figure 2. The chambers have an external width of 864 mm and height of 406 mm (StormTech SC-310 chambers). Figure 2 shows the 2 north-south lines of chambers and the location of monitoring bores.

The units were installed 80 m apart, both aligned north-south to discharge into the Park Avenue drain 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 Figures 2 and 3.

The installation of the trial site occurred in mid-2009. During winter 2009 the Park Avenue drain 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 drain 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.

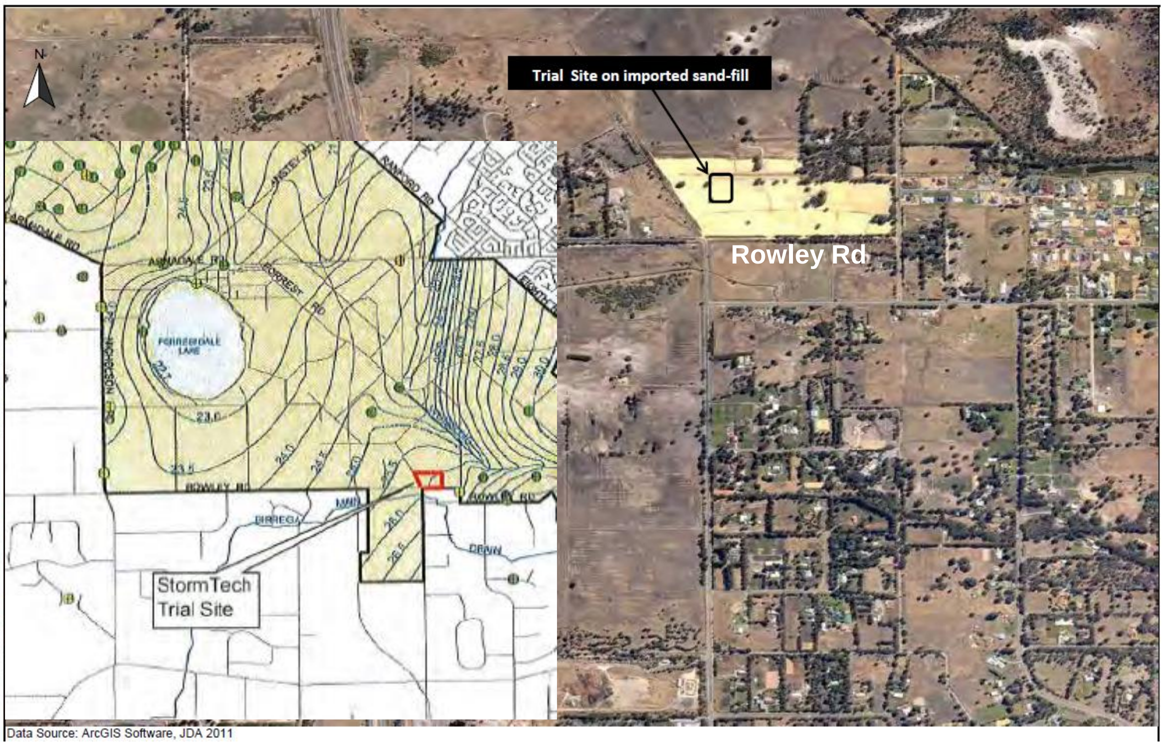

Figure 1: Imported Sand-Fill Trial Site Location Plan

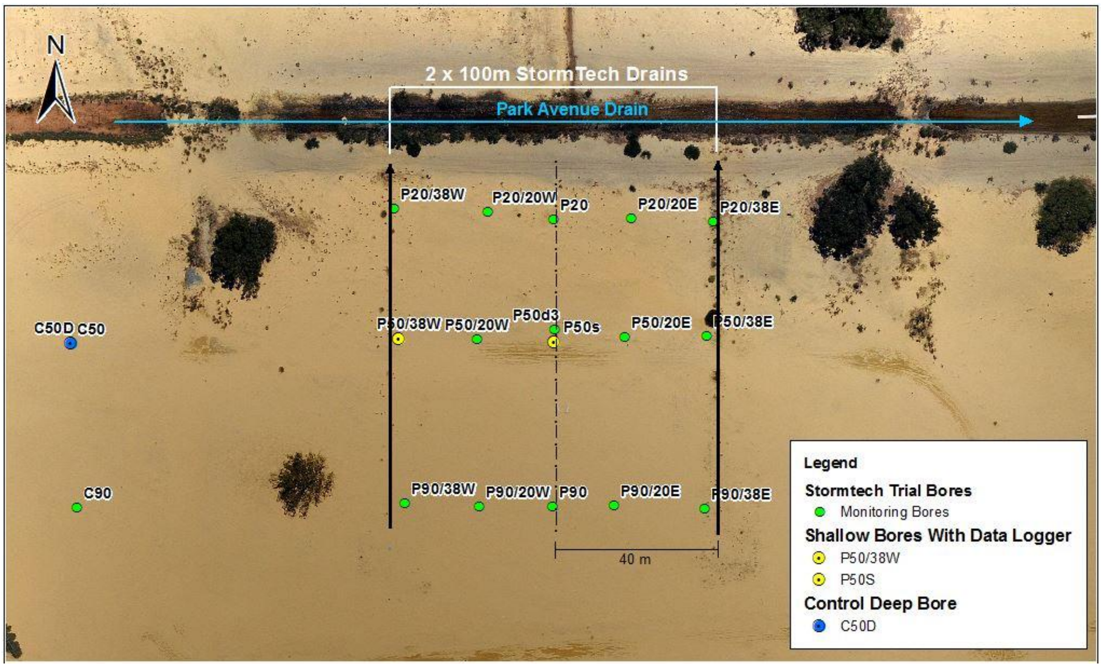

Figure 2: Monitoring Bores and Layout

3. 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 data-loggers 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 Figures 3 and 4. Figure 4 shows that 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 2010 hail and rain event, a saturated zone (perched water table) did develop within the imported sand-fill. In comparison Figure 5 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 6 shows contours of the perched and regional water table on 15 July 2010 when the perched water table was at its highest. Figure 7 shows the regional groundwater level to be approximately 22 mAHD, compared with the perched water table at approximately 26.5 mAHD.

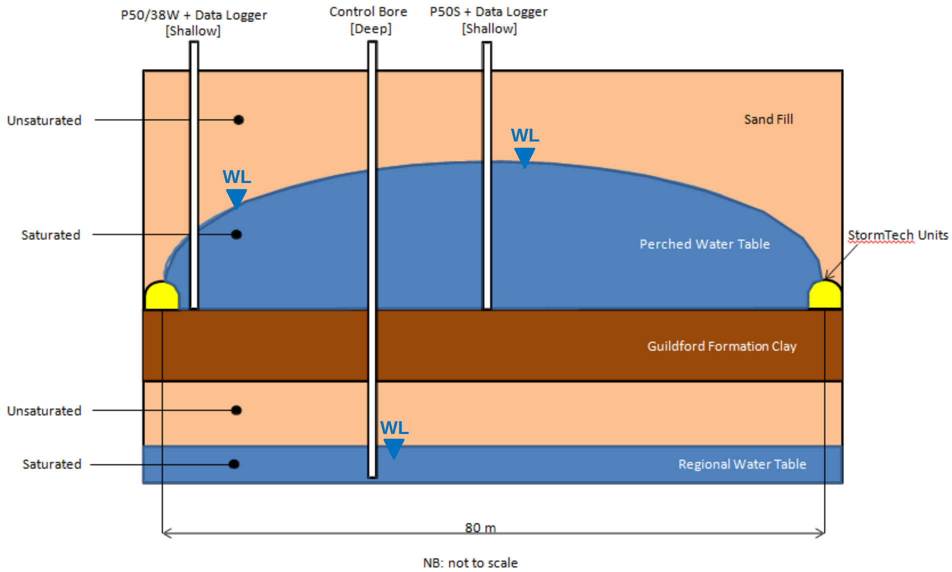

Figure 3: Schematics of Trial Site

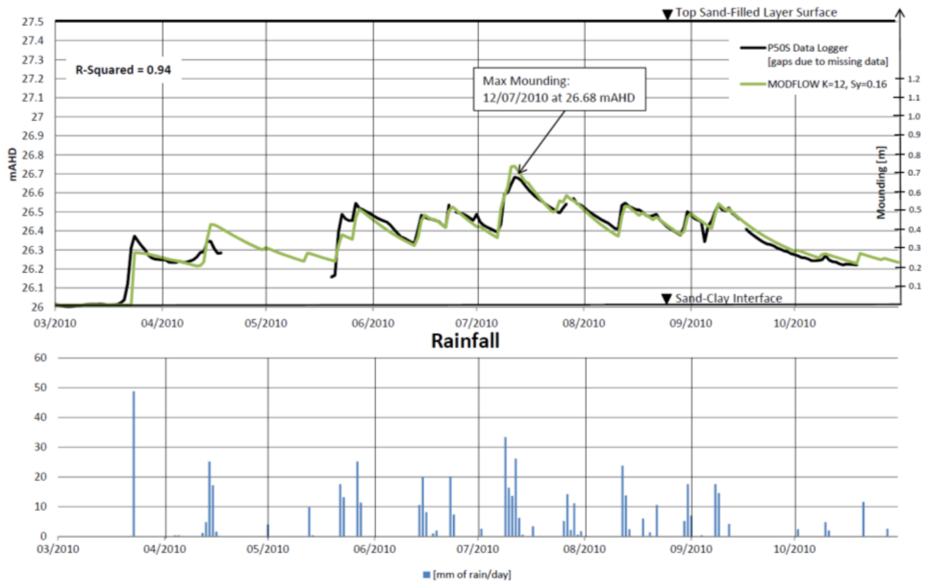

Figure 4: Water Level in 2010 at the Centre between Parallel Subsoil Drains

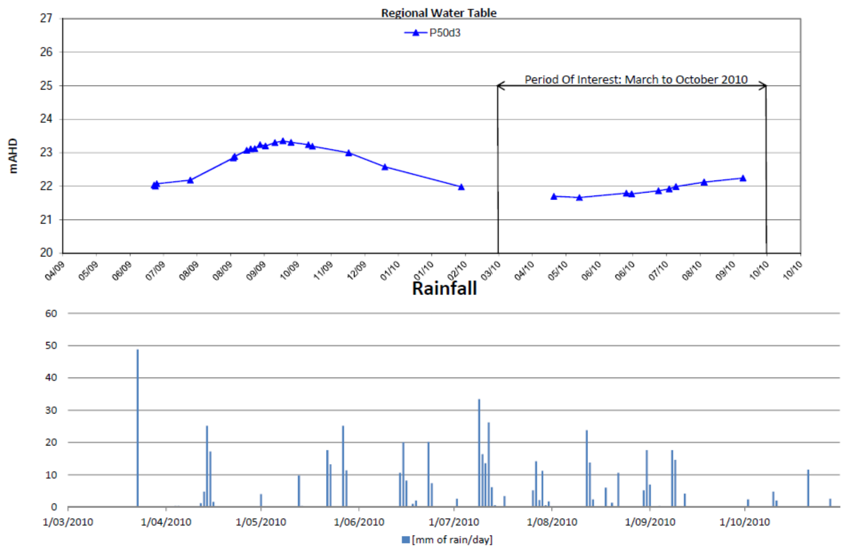

Figure 5: Water Level Data in 2010 at the Regional Water Table Bore P50D3

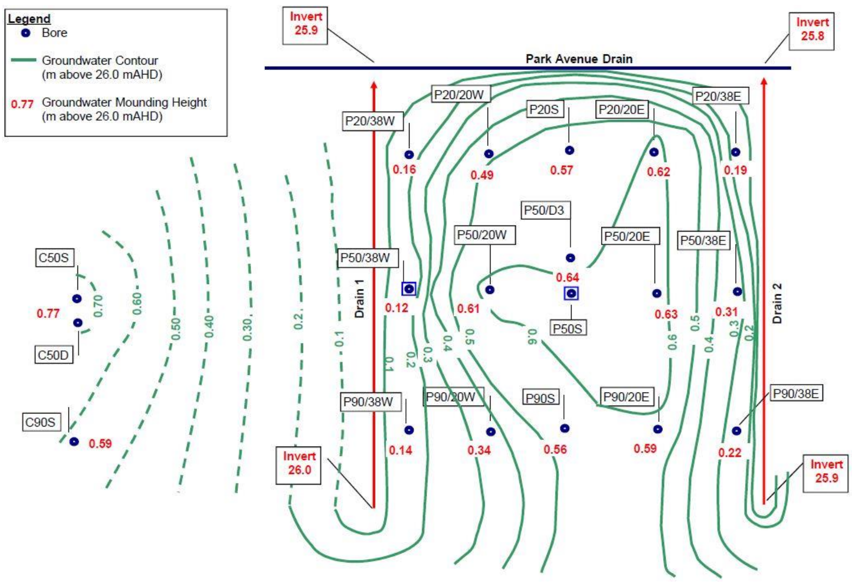

Figure 6: Perched Water Level Mounding 15/07/2010

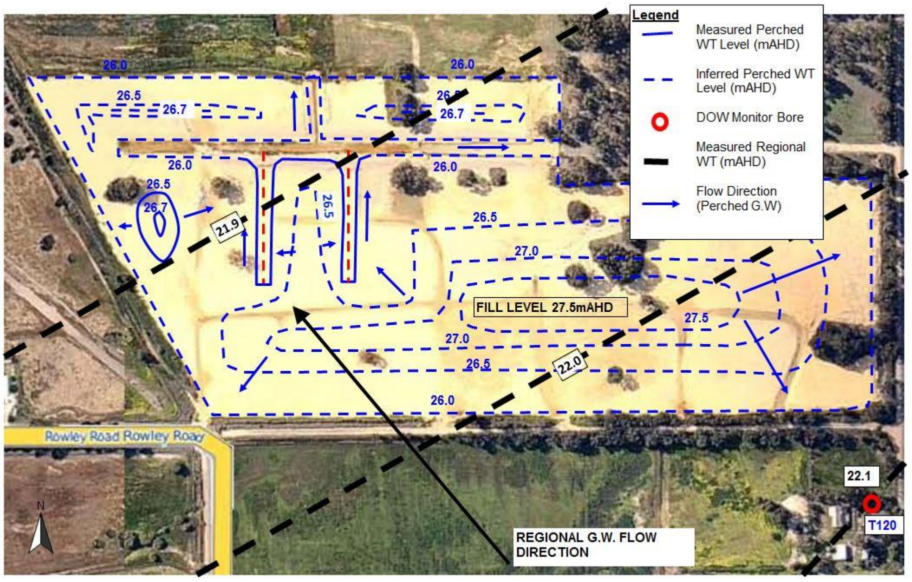

Figure 7: Perched and Regional Water Table Contours 15/7/2010

4. PERCHED WATER TABLE MOUNDING HEIGHT

Figure 4 shows that the perched water table mounding height increased during winter 2010 to a maximum of 0.68 m on 12 July 2010. Figure 4 also 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 events.

This is in contrast to the commonly held belief that the mounding between subsoil drains occurs due to a heavy rainfall event such as the 24hr 5yr ARI storm event. Figure 4 clearly shows that for subsoil systems draining perched groundwater, 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.

5. GROUNDWATER MODEL OF PERCHED WATER TABLE

A MODFLOW saturated groundwater flow model was established over the 8,000 m^2 trial area. The model uses a one day time step for a total of 245 days, from 1 March to 31 October 2010.

Boundary conditions were set as fixed head along the StormTech drain lines and along the Park Avenue drain. For the southern boundary, a no flow boundary was assumed – this was based on estimated contours as shown in Figure 6, which shows that flow is generally perpendicular to the subsoil drains.

The bare nature of the sand-fill together with the absence of both civil infrastructures and vegetation suggest there is negligible rainfall interception or evapotranspiration occurring on the trial site: a rainfall recharge rate of 80% was consequently adopted. The recharge used within the MODFLOW model was therefore the daily rainfall depth multiplied by 80%. MODFLOW does not have an unsaturated engine for the movement of water above the water table so this recharge is applied to the top layer of the model.

Important aquifer parameters used within the MODFLOW model are the specific yield (S_y) and hydraulic conductivity (K). The movement of water within the soil matrix is governed by these parameters. The specific yield relates to the fraction of the aquifer volume that can be yielded when all the water drains under gravity. For sandy soils a specific yield ranges from 0.1 to 0.2 (Davidson, 1995). Hydraulic conductivity describes the ease with which water can move through soil and defined as the rate of flow under unit hydraulic gradient.

Also of importance is the porosity (n) which is defined as the ratio between the volume of the voids and the total volume of the soil, with typical values of between 0.1 and 0.3 for sand.

The model was calibrated and adopted parameters are presented in Table 1. Specific yield is within the range proposed by Davidson, (1995). The values for hydraulic conductivity and porosity are within the range that is generally accepted for a sand soil.

Table 1: MODFLOW Calibration Parameters

Recharge	*Type* *Source* *Rate*	Rainfall, Daily Data [mm/unit time] BoM 80%
n	*Value*	0.25 (25%) [dimensionless]
S_y	*Value*	0.16 (16%) [dimensionless]
K	*Value*	12m/day

Figure 4 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. A correlation of r^2=0.94 was observed between the observed and modeled values.
Figure 8 shows daily measurements for the perched groundwater table plotted against the simulated levels also on a daily time interval; the plot generally shows calibration within 0.1m of the mounding. The largest difference is indicated on Figure 8 for 22 March 2010 which has an error of approximately 0.3m due to the rapid rise of the perched water table and the use of a one day time-step used in the model.

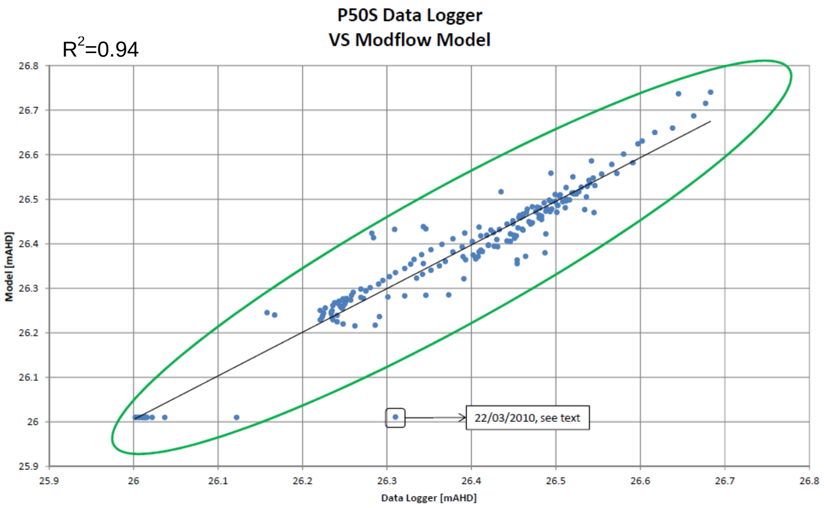

Figure 8: MODFLOW Model Calibration Plot at Centreline of Subsoil Drains

6. PERCHED WATER TABLE MOUNDING POST-DEVELOPMENT

The calibrated MODFLOW groundwater model has been used to apply a post-development land use scenario. The Perth Regional Aquifer Modelling System (PRAMS) uses a rainfall recharge rate of 62% (PRAMS, 2009) for urban residential land use. However, in areas with shallow groundwater table and low infiltration capacity (such as the current Study Area), lot connections to the local stormwater drainage system are used. This results in a lower recharge to groundwater. As an example, a lower rainfall recharge rate of 40% has been used to model the post development condition. A wet rainfall year was modelled, based on the wettest year at the Anketell BoM rainfall station since 2002. This wet year (2008) recorded 776 mm between 1 March and 31 October.

Figure 9 shows the MODFLOW estimation of the perched water table mounding centreline between the parallel drains. This shows a peak of 0.52m on 2 August 2008.

Despite a different rainfall temporal 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, with the maximum occurring in July/August of the year.

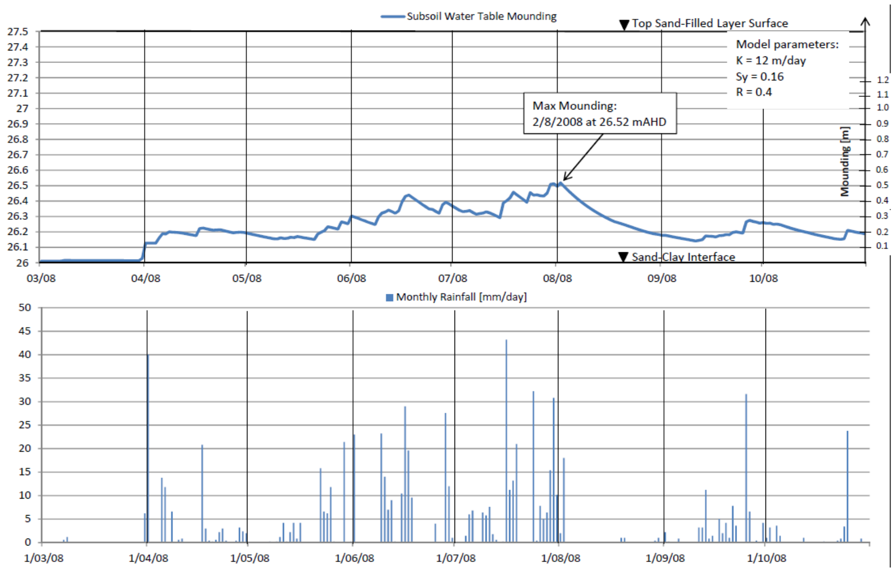

Figure 9: Post-Development Mounding: Wet Year (2008)

7. 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 above the 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 the pre-development bare sand scenario.

A groundwater model (MODFLOW) was calibrated to the observed dataset with realistic values of soil parameters for a pre-development scenario.

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

It is concluded that this set of data and the calibrated groundwater model provide an excellent basis for estimating perched water table mounding heights for a commonly used drain spacing in sand fill on Guildford Formation, provided that the sand material and compaction status are similar.

It is acknowledged that further work is required to test the sensitivity of the model to soil and rainfall parameters to allow model accuracy to be estimated.

Further work exploring post development scenarios (varying drain spacing, aquifer & sand-fill parameters, development densities and rainfall recharge) will also be required.

8. ACKNOWLEDGMENTS

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.

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