GROUNDWATER MODELLING OF MOUNDING BETWEEN SUBSOIL DRAINS

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ABSTRACT:

On the Swan Coastal Plain subsoil drainage has been used for decades in urban development 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 the application of the IPWEA (2016) [1] Specification Separation Distances for Groundwater Controlled Urban Development Methodology to Subsoil Drains. The specification was developed to provide consistency and improve technical rigour in the design and application of subsoil drainage. It develops agreed separation distances and an agreed methodology for the estimation of engineered groundwater systems. The specification is currently a draft, allowing for industry feedback.

The paper describes groundwater modelling of subsoil drainage systems using 2D vertical slice and 3D models with rainfall predictions based on DoW (2015) [2] future median climate scenarios over a 30 year time period centered on 2030.

Two examples of the application of the methodology are provided, the first applying to residential lots and the second to public open space (POS).

The paper also presents results for several recharge scenarios for residential lots using the 2D vertical slice model, including:

- *Uniform rainfall recharge;*
- *Non-uniform recharge with infiltration devices at front and rear of Lots;*
- *Non-uniform recharge with infiltration devices at front of Lots.*

The impact of soil hydraulic conductivity on subsoil mounding is also discussed.

KEYWORDS: Subsoil drainage, groundwater modelling, separation distances, future median climate scenario

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1 INTRODUCTION

In general, the soils of the Swan Coastal Plain allow for the use of subsoil drainage to control groundwater levels for urban development where water levels are close to the surface. The sandy, permeable nature of the soils and the low rainfall of the region result in shallow mounding of groundwater between subsoil drainage lines as excess water discharges to the subsoil system. Historically, subsoil drainage systems have been installed, with little in the way of calculation. Generally no failures of the system have been observed, as soil hydraulic conductivity (K) was high, and depth to water was sufficiently deep enough so that excessive mounding between the drains did not intercept the surface.

However, as development moves into areas with less permeable soils or where groundwater is close to, or at, existing natural surface and fill costs become significant, more accurate determination of the groundwater mounding becomes critical. In these areas, where separation to groundwater mounding becomes minimal, risk of failure (prolonged periods with mound close to the surface) increases.

To provide more certainty the Institute of Public Works Engineers Australasia (IPWEA) released the draft specification Separation Distances for Groundwater Controlled Urban Development Methodology to Subsoil Drains [1]. The paper looks at implementation of the IPWEA guideline, some case studies, and an investigation into the impact of spatial recharge distribution.

2 IPWEA (2016) GUIDELINES

The aim of the IPWEA guidelines is as follows:

> *"The objective of the groundwater separation distance guidelines is to provide criteria (specifications) for groundwater separations appropriate to acceptable levels of risk and amenity for critical elements of built form and infrastructure and provide guidance regarding appropriate methodology (design) for assessment and approval of groundwater levels and separations."* [1]

The document provides guidance on the degree of detail required for groundwater modelling during different stages of the planning process. This might include no modelling or analytical equations at district water management reporting level, to possibly 3D detailed groundwater modelling at urban water management reporting level.

Rainfall recharge is main input to the system and the document provides the following instruction for rainfall requirements:

> *"A 30 year daily timestep rainfall record is to be used to develop a probability density function from which the required level of service can be selected. This data should be sourced from the Department of Water.*
> *Rainfall predictions to be used as modelling inputs should be based on the Department of Water's future median scenario, as outlined in the Selection of future climate projects for Western Australia (DoW, 2015) [2]."* [1]

An example of the wet, median and dry scenarios for the Perth Airport rain gauge station is shown in Figure 1.

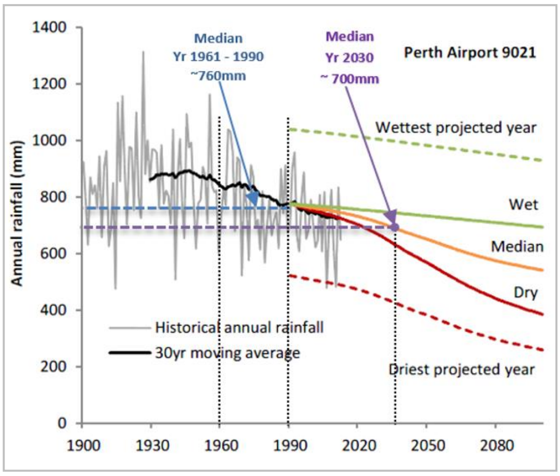

Figure 1: *Future rainfall scenarios for Perth Airport*

The guideline specifications do not address buildings, roads and services as these are covered by other codes or guideline documents. The IPWEA guideline is more relevant to drainage infrastructure, private space (lots) and public open space.

The specification for groundwater separation varies depending on soil type, lot size, location of drainage storage, or the function of the open space. Table 1 provides a summary of the draft specifications, and Table 2 provides separation distance for turfed open space.

***Table 1**: IPWEA (2016) Draft Specifications*

Built Form Type	Phreatic Surface AEP (1 in X)	Separation Criteria (mm)
Drainage (infiltration)		
Underground	50	0
Surface (vegetated)	50	300
Surface (turfed)	Default to Recreational POS specification	
Private Space		
Residential 400-800m^2	50	Note 1
Residential <400m^2	50	Note 2
Public Open Space		
Nature – local	The requirement for nature spaces is dependent on its characteristics and ecological water requirements	
Nature – neighbour		
Nature – district		
Nature – regional		
Recreation – local	50	Table 2
Recreation – neighbour	50	Table 2
Recreation – district	20	Table 2
Recreation – regional	20	Table 2
Sport – local	50	Table 2
Sport – neighbour	20	Table 2
Sport – district	20	Table 2
Sport – regional	10	Table 2

Note 1: 300mm of coarse sand applied to anticipated gardens areas in the rear of lots above the 50% AEP phreatic surface.
Note 2: 150mm of coarse sand applied to anticipated gardens areas in the rear of lots above the 50% AEP phreatic surface.

***Table 2:** Separation Distance – Turfed Open Space*

Soil Type [1]	Separation Distance
Gravel – Coarse	150mm
Gravel – Medium	150mm
Gravel – Fine	200mm
Sand – Coarse	300mm
Sand – Medium	450mm
Sand – Fine	650mm

Note 1: Classification of soil type is based on Table A1 of AS1726-1993 geotechnical site investigations.

3 FUTURE CLIMATE PROJECTIONS FOR WA

The Department of Water (now Department of Water and Environmental Regulation – DWER) report on future climate projections [2] investigated variation in climactic parameters such as rainfall, temperature, relative humidity, radiation, evaporation and evapotranspiration, for dry, median and wet scenarios, for the 2030, 2050, 2070 and 2100 time horizons. A set of standard monthly climate anomalies was developed for the parameters. The climatic anomalies vary spatially. The report uses a baseline dataset for rainfall of the 1961 to 1990 observed rainfall. The monthly anomalies are applied to the baseline data to generate a synthetic 30 year rainfall record for the time horizon that is to be assessed.

An example is shown in Figure 2 which presents the synthetic record for the Armadale rainfall station (no. 9001). This uses the 2030 time horizon, and compares the baseline data with the standard anomalies applied for that region. Also shown is the percentage change in rainfall resulting from the predicted climate change.

For the modelling of subsoil drainage in the application of the IPWEA guideline, the 2030 time horizon was used, with the method above applied to generate synthetic 30 year rainfall records.

4 CASE # 1 – RESIDENTIAL LOTS

Case Study 1 is a residential development located south of Perth near Busselton. The proposed development has a road spacing of approximately 70m, with subsoil drainage located within the road reserves. Lots will be less than 400m^2 in size. Consistent with local authority requirements, residential lots will be required to infiltrate the first 15mm of rainfall within the lot, using soakwells or other infiltration devices.

The native soil is approximately 1m of sand overlying clay material. Groundwater levels are close to the sand / clay interface, with minimal seasonal variation. It is proposed to import sand fill to provide greater separation to groundwater. The saturated hydraulic conductivity of the native sand (K_b) is estimated to be between 1 and 5m/d. The saturated hydraulic conductivity of the sand fill (K_a) is expected to be between 1 and 10m/d, with a likely value of 5m/d. For the purposes of modelling, the native and fill hydraulic conductivity were assumed to be the same.

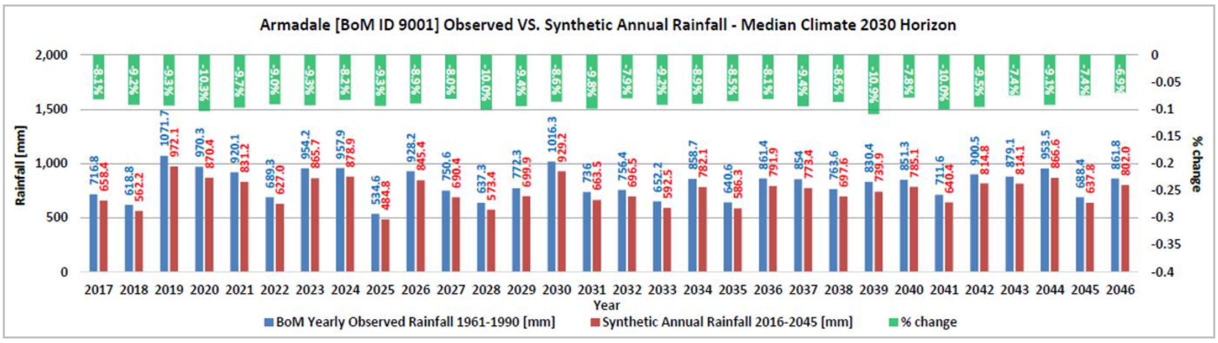

Figure 2: *Armadale Rainfall Station Synthetic 30 year Record for Median Climate 2030 Horizon*

Based on Table 2, the design criteria for the residential lots would be a minimum separation of 150mm of coarse sand applied above the 50% AEP phreatic surface. This is illustrated in Figure 3.

The synthetic rainfall record was generated based on the observed rainfall record at Busselton. A rainfall recharge to groundwater of 70% was used, applied uniformly over the lots. The inverts of the subsoil drainage are proposed to be slightly above the sand / clay interface.

A groundwater model with a daily timestep was developed using FEFLOW which incorporates the soil stratigraphy, subsoil drain layout, aquifer parameters and recharge and rainfall rates.

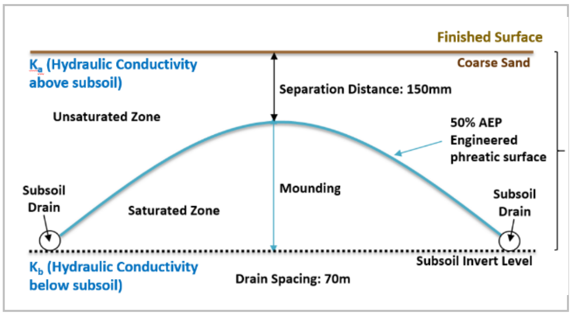

Figure 3: *Schematic showing groundwater mounding between subsoil drains for Case Study 1.*

Figure 4 shows the time series of the resulting groundwater mounding (above subsoil drainage invert level) at the midpoint between the subsoil drainage lines (this being the point of maximum mounding). The top panel shows the daily data plotted, while the lower panel shows the maximum value for each year of the simulation.

Three scenarios for sand fill hydraulic conductivity are shown – 1, 5 and 10m/d. It can be seen that increasing hydraulic conductivity decreases groundwater mounding, as expected. The modelling indicates that the 50% AEP mounding is 0.8m for the case where sand fill hydraulic conductivity (K_a) is 5m/d. For the scenario using a K_a of 1m/d, the 50% AEP mounding is 1.21m above the subsoil drain invert level. This provides an indication of the range of expected mounding, where there is some uncertainty in the expected hydraulic conductivity of the soil. Based on the IPWEA guidelines and adopted K_a, a finished surface 0.95m (0.8 + 0.15) above the subsoil invert would be acceptable.

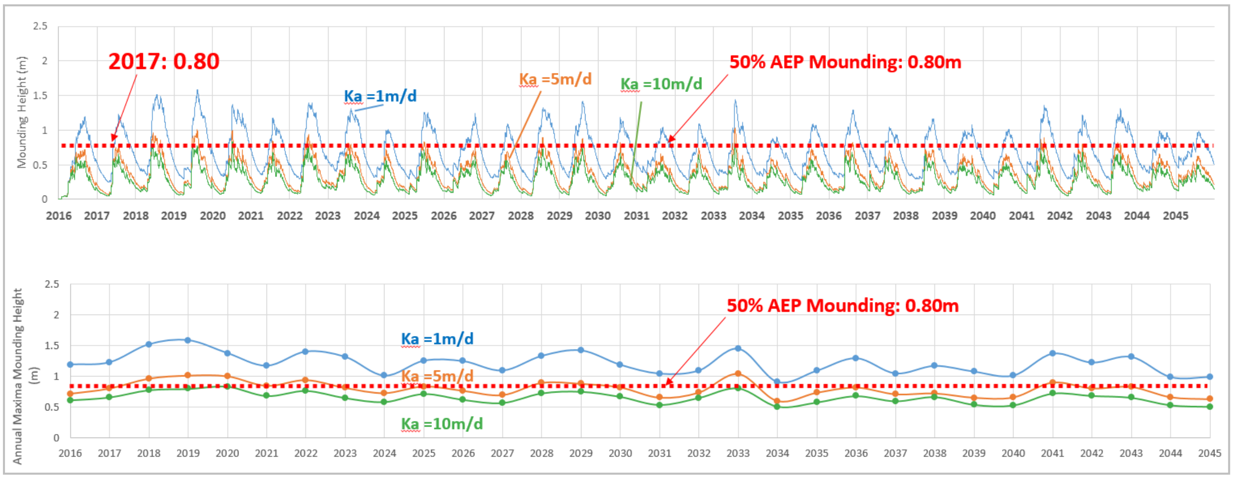

Figure 4: *Groundwater modelling results for Case Study 1*

5 CASE # 2 – PUBLIC OPEN SPACE

Case Study 2 is in a residential development in the City of Armadale. As part of the development, it is proposed to locate a school and a shared oval (between school and community) together.

The surface geology of the site is shallow sands (generally less than 0.5m) over clay. Perched groundwater occurs during winter months. Therefore a subsoil drainage system is required to manage perched groundwater levels, and sand fill will be required to be imported to provide adequate separation to groundwater. Subsoil drainage lines occur in the road network surrounding the oval and school (servicing the residential lots).

Figure 5 shows the perimeter subsoil drainage, which conveys water to the north of the oval. To the west of the oval will be club rooms and parking (oval services), as well as a waste water pumping station in the North West corner.

Figure 5: *Case Study 2 Layout and Perimeter Subsoil Drainage*

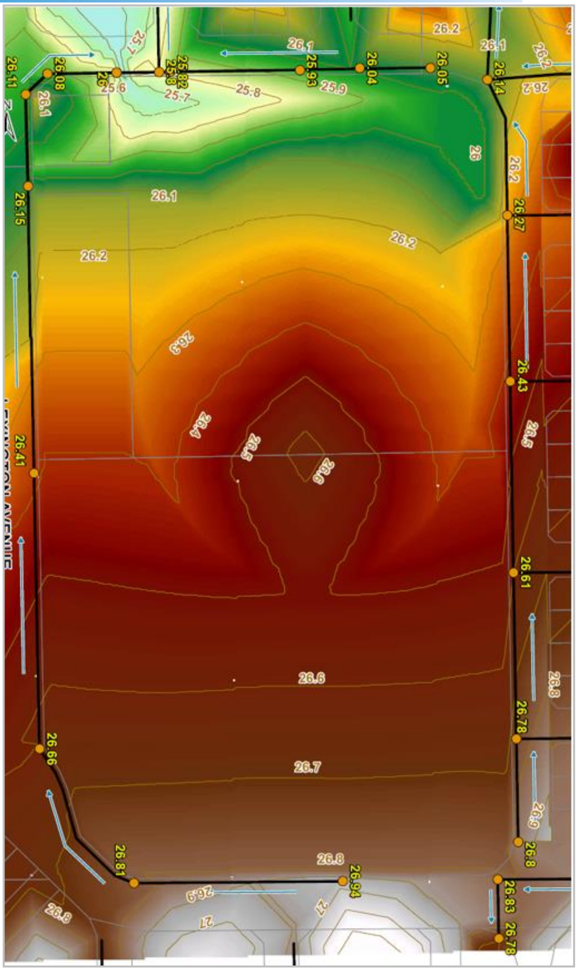

Figure 6: *Clay Grading Contours*

It is proposed to grade the existing clay material prior to placement of sand fill material. Figure 6 shows the preliminary contours of the clay grading, with grading from south to north, as well as west and east towards the perimeter subsoil drainage.

The oval is classed as sports at neighbourhood scale in Table 1, therefore the 20% AEP groundwater surface should be used for design. Assuming that medium grained sand will be used for fill, Table 2 specifies that a separation distance of 450mm above the 20% AEP groundwater surface is required.

The synthetic rainfall record was generated based on the observed rainfall record at Armadale using the 2030 rainfall anomalies. A rainfall recharge to groundwater of 90% was used for the oval and the school, on the basis that there would be little connection to the street drainage, and so most rain events would infiltrate. For the proposed oval services, a recharge value of 65% was adopted.

The inverts of the subsoil drainage are proposed to be at the clay subgrade, and it is assumed that the clay subgrade is impermeable. The imported sand fill was assumed to have a saturated hydraulic conductivity of 5m/d.

A 3D groundwater model was developed using FEFLOW which incorporates the soil stratigraphy, subsoil drain layout, aquifer parameters and recharge and rainfall rates.

The final subsoil drainage layout presented in Figure 7 followed several iterations of the model, modifying the spacing of the subsoil drainage lines. The objective of the design of the subsoil system was to control groundwater mounding such that a sand fill layer of 800mm would be sufficient to meet the IPWEA guidelines. This was primarily due to the cost of additional fill versus the cost of additional subsoil drainage, with subsoil drainage providing a lower cost option while still providing sufficient separation to groundwater. The subsoil drainage layout under the school site is preliminary only, and will be dependent on final planning of the school.

Figure 8 shows the time series results of the modelling at a location midway between subsoil drainage lines (Obs1 on Figure 7) where maximum mounding is observed. The top panel shows the daily data plotted, while the lower panel shows the maximum value for each year of the simulation. The 20% and 50% AEP levels of 26.77mAHD and 26.73mAHD respectively are shown on the lower panel, along with the proposed surface elevation of 27.22mAHD.

Figure 7: *Subsoil Drainage Layout*

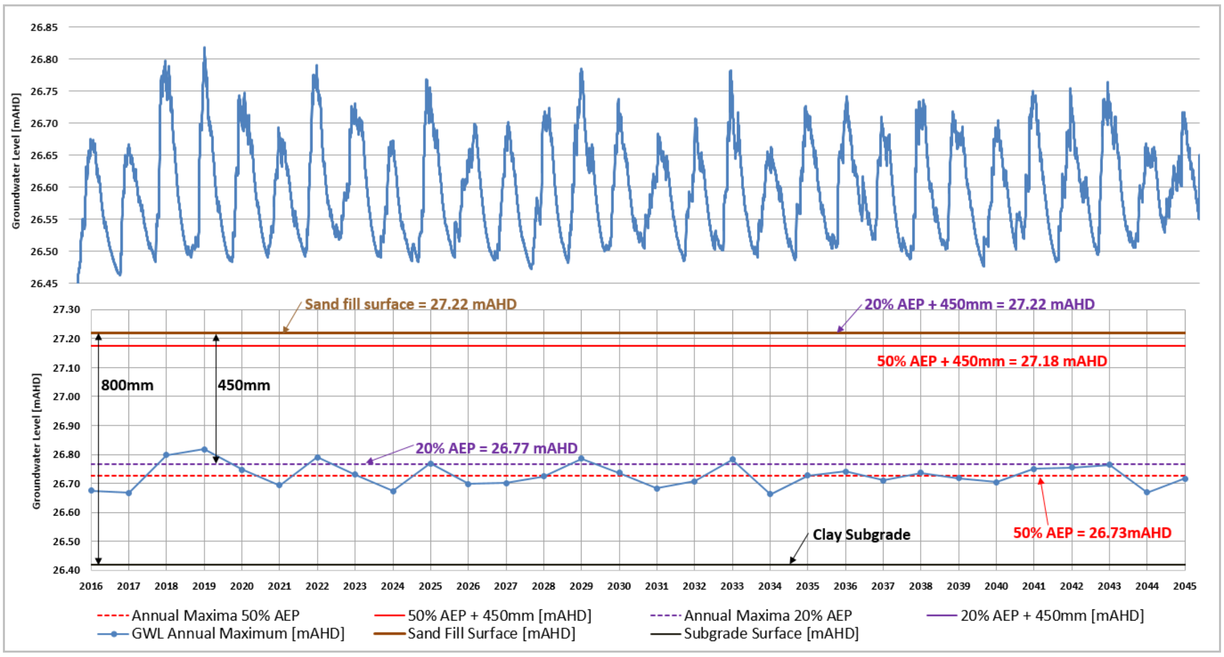

Figure 8: *Groundwater modelling results for Case Study 2*

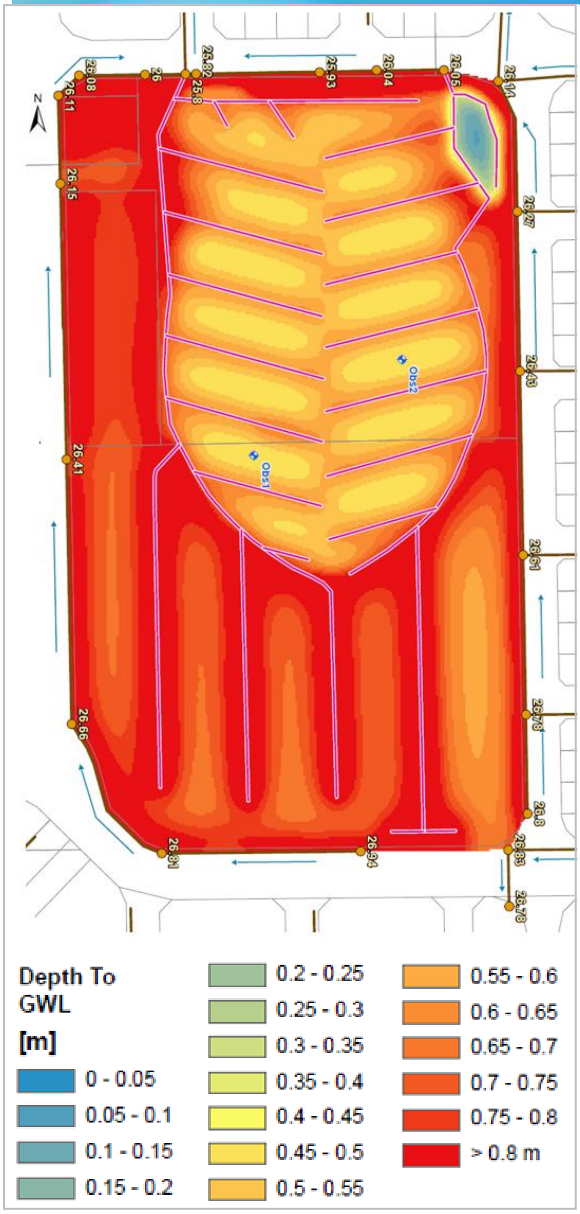

Figure 9: *Case Study 2 – Depth to 20% AEP Groundwater Level*

At this location, the separation between the 20% AEP level and the proposed surface elevation is greater than the 450mm separation distance specified from Table 2.

Figure 9 shows the depth to the 20% AEP groundwater level from the proposed surface elevation. The depth is greater than 450mm across the oval and school site, and as such meets the IPWEA guidelines criteria. Separation distance is low in the top corner as this is the location of a drainage basin, and is not turfed.

6 IMPACT OF RAINFALL SPATIAL DISTRIBUTION

In many cases, modelling of subsoil mounding between subsoil drainage lines, such as that in Case Study 1, have assumed a uniform rainfall distribution between the drainage lines.

In reality however, recharge from rainfall on urban residential lots will be concentrated at the front and/or rear of lots where soakwells or other infiltration devices are located. Therefore three rainfall recharge scenarios have been considered:

- Scenario 1 – uniform recharge over the lot;
- Scenario 2 – Soakwell at the front and rear of the lot; and
- Scenario 3 – Soakwell at the front of the lot only.

A groundwater flow model was developed to include the spatial distribution of rainfall. The model simulates an 80m spacing between subsoil drains. For Scenarios 2 and 3, the front 7m and rear 4m of lots are modelled as permeable garden or turf areas. Rainfall from house roof areas was concentrated across 2m wide areas (simulating soakwells) at front and/or rear of lots (depending on scenario). There was no recharge from rainfall directly under the house areas. Figure 10 provides a schematic that shows the distribution for Scenario 2.

Figure 10 shows the peak mounding resulting from an average rainfall year for the three scenarios. The black line shows the mounding for Scenario 1 – uniform recharge. The dark blue line shows the mounding for Scenario 2, and the light blue shows Scenario 3.

The Scenario 2 groundwater profile shows the peaks under the soakwells, where recharge is concentrated. Peak mounding is slightly lower than Scenario 1, with the peak occurring under the rear soakwell.

The Scenario 3 groundwater profile is skewed to the front of the lots, as is to be expected. The groundwater level at the rear of the lots is significantly lower than Scenarios 1 and 2. The peak level under the front soakwell is approximately 25% lower than Scenarios 1 and 2 peak levels.

The lower peak levels are a result of the shorter travel path from the soakwell recharge to the subsoil drain. This also implies that subsoil discharge for Scenario 3 will be peakier and the rate higher than Scenarios 1 and 2.

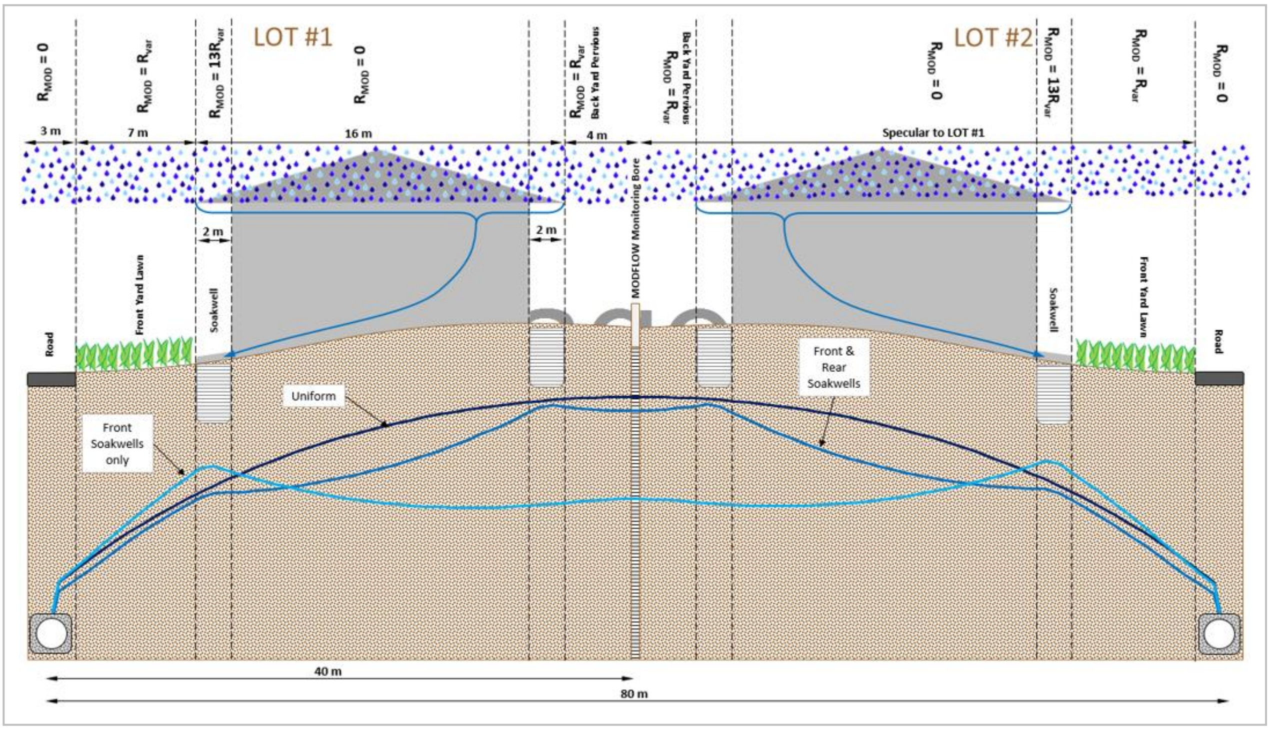

Figure 10: *Assessment of Different Rainfall Spatial Distributions on Groundwater Mounding*

7 CONCLUSIONS

These case studies provide an example of the implementation of the draft IPWEA guidelines for groundwater separation for controlled groundwater in urban settings.

The studies apply the DoW (2015) Future Climate Scenarios, as required by the guidelines, to generate the appropriate level AEP for application.

Case study 1 provides an example of groundwater mounding under urban lots using a 2D vertical slice groundwater model. The modelling gives an indication of the sensitivity to the saturated hydraulic conductivity.

Case study 2 provides an example of groundwater control under POS (in this case an oval) using a detailed 3D groundwater model.

The exploration of the impact of spatial distribution of rainfall recharge on the groundwater mounding profile indicates that mound height is influenced by the pattern of rainfall spatial distribution. This illustrates the benefit of soakwells at the front of lots to reduce peak mounding.

REFERENCES

[1] IPWEA. Draft Specification: Separation distance for groundwater controlled urban development, 2016.

[2] Department of Water. Selection of future climate projections for Western Australia, Water Science Technical Series, report no. 72, 2015.