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Project 39787.03
23 December 2021
R.001.Rev0
WW:jrc

Attention: Lex Tall

Email: lex@swrd.com.au

Groundwater Assessment
Proposed Residential Subdivision
Phillip Drive, South West Rocks

1. Introduction

This report presents the results of additional site assessment undertaken for a proposed residential subdivision at Phillip Drive, South West Rocks. The work was carried out for SW Rocks Developments Pty Ltd with reference to our Proposal 39787.03.P.001.Rev0 dated 7 December 2021.

The site has been subject to several previous investigations and reports by Douglas Partners, the most recent of which was a Review of the Groundwater Management for Concept Plan (DP, 2016). The scope of this assessment was as follows:

- Brief review of DP's 2016 report;
- Site walkover by an experienced engineer to assess and observe site features relevant to the proposed development, including gauging of groundwater levels in serviceable wells;
- Brief comment on the suitability of the general groundwater measures previously recommended on the basis of the updated development plan (provided by the client); and
- Recommendations for additional investigations to progress studies.

This report is an addendum to DP (2016) and should be read in conjunction with the 2016 report which is appended to this report. This report does not directly assess groundwater management measures for Stage 1 of the development as these were addressed in a 2013 report by Douglas Partners (DP, 2013), although it does include site observations in Stage 1 as these are relevant to assess conditions on the other parts of the site.

2. Background

The site has been subject to several previous investigations and reports by Douglas Partners, the most recent of which was a Review of the Groundwater Management for Concept Plan (DP, 2016).

DP (2016) provided a review of data collected to the date of the report on site, presented a conceptual groundwater model for the site and reviewed the concept design stormwater management plan for its ability to replicate natural groundwater processes on site. The assessment concluded it would be possible to provide a reasonable replication of the existing groundwater flow downstream of the site, subject to appropriate detailed design including development of a calibrated groundwater model and simulation of the proposed development.

3. Proposed Development

The current proposed concept plan layout is shown in Figure 1 below and the previously proposed layout including the concept stormwater management system, which was the subject of DP (2016), is shown in Figure 2. The previously proposed water management system included a series of drains shown in blue as well as infiltration swales shown in pink on Figure 2.

Figure 1: Current Proposed Concept Plan

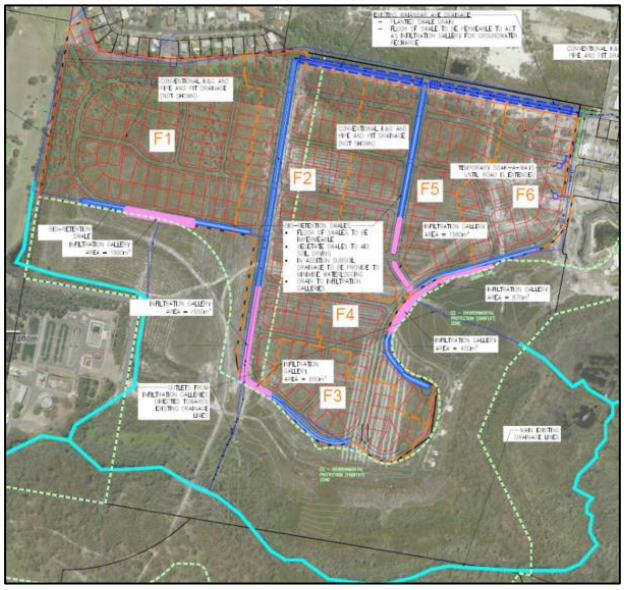

Figure 2: Previous concept plan with concept water management shown

The current concept plan seems to have a similar footprint to the previous arrangement. It is understood that no details of the water management system are available for the current lot layout.

4. Site Inspection

The site was inspected by a Principal Groundwater Engineer on 17 December 2021 and included the following:

- Drive and walk over assessment of key features including existing groundwater wells and surface water features;
- Dipping of groundwater levels in the accessible and serviceable wells; and
- Survey of surface water levels at key locations using differential GPS.

The site was observed to be in a similar condition to that observed in previous site inspections from 2007, apart from the north-east corner where construction of Stage 1 has commenced.
Existing groundwater wells at Bores 2, 7, 9 and 10 were located and the water levels within the wells measured. There was extensive surface water evident in various drains and low-lying features across the site indicating groundwater at or near the surface across much of the site (Figure 3 and Figure 4).

Figure 3: Surface water near Bore 7

Figure 4: Surface water in shallow drain beside access road

The various surface drains were observed to be actively flowing into Saltwater Creek and Saltwater Lagoon. The largest drain, a north-south oriented drain located on the central parts of the site was producing the most flow, as shown in Figure 5 below. The water in this drain was observed to be of very low turbidity apart from natural tannin staining, although Saltwater Creek at this point was quite turbid, likely due to urban runoff occurring upstream of the site. A secondary drain was observed feeding into the lagoon further to the east with much lower flows and similar low turbidity water.

Figure 5: Surface water from main north-south drain entering Saltwater Creek

Figure 6: Surface Water Drainage into Lagoon

The mouth of Saltwater Creek was openly flowing into the ocean at the time of the inspection.

Figure 7: Mouth of Saltwater Creek openly flowing

In the north-east corner of the site construction of Stage 1 of the development has commenced with stripping of topsoil evident. The previous monitoring wells at Bores 8 and 11 had been removed by the site works although the groundwater levels were evident from the presence of ponded water forming at the base of the excavations (Figs 8 and 9). Ponded water levels were measured to range from RL 2.7 AHD along the southern edge of Stage 1 near the approximate location of the previous Bore 11 to RL 3.9 at the northern edge of the proposed lots.

Figure 8: Water ponding near southern edge of clearing

Figure 9: Water ponding at proposed lots

5. Comments

5.1 Groundwater Level observations

Observed groundwater levels are presented in Table 1 and compared to the previously measured range of water levels from April 2014 to June 2016.

Table 1: Summary of Groundwater Levels

Bore	Surface Level (AHD)	Previously Observed April 2014 to June 2016						Groundwater Level 17 December 2021 (AHD)
		Range of Groundwater Level/Depth		Average Groundwater Level/depth		Typical Ceiling Level		
		Level (AHD)	Depth (m)	Level (AHD)	Depth (m)	Level (AHD)	Depth (m)	
1A	4.2	3.3 to 4.1	0.1 to 0.9	3.4	0.8	3.9	0.3	**3.5***
7A	3.9	<3.1 to 4.0	0 to >0.8	3.5	0.45	3.9	At surface	**3.9**
9	4.45	3.2 to 4.2	0.25 to 1.25	3.7	0.8	4.2	0.25	**4.2**
2	3.3	2.0 to 3.0	0.3 to 1.3	2.5	0.8	2.9	0.4	**3.0**
8	3.6	0.8 to 2.1	1.5 to 2.8	1.2	2.4	NA	NA	**3.3****
10	3.1	1.7 to 2.9	0.2 to 1.4	2.1	1.0	NA	NA	**2.3**
11	3.1	<2.4 to 3.1	0 to >0.7	2.5	0.6	3.1	0	**2.7**
Saltwater Lagoon	NA	0.5 to 2.4	NA	0.9	NA	NA	NA	**1.0**

Notes to Table 1:

* In drain adjacent to previous Bore 1 well location

** Ponded water at surface near previous Bore 8 well location (Bore 8 well has been removed by construction activity)

The results indicated groundwater levels were at the upper end of the range of those previously measured on site as shown on Figure 10, in particular on the northern parts of the site where levels were often at or near previously identified ceiling levels (DP 2016). This is consistent with the site observations of the surface drainage features actively flowing and thereby controlling the upper groundwater levels across most of the site. This is also consistent with the conceptual groundwater model (DP, 2016) which identified this drainage effect limiting upper groundwater levels following above average rainfall events, as occurred in November 2021 prior to the site inspection.

The surface water level in the vicinity of the previous Bore 8 was above previously measured water levels at Bore 8, however Bore 8 was screened at depth below a clay layer and the observed water level is likely to be perched above this level. The shallow groundwater levels in the Stage 1 area (Figure 9) highlight the need for appropriate surface and subsurface drainage measures.

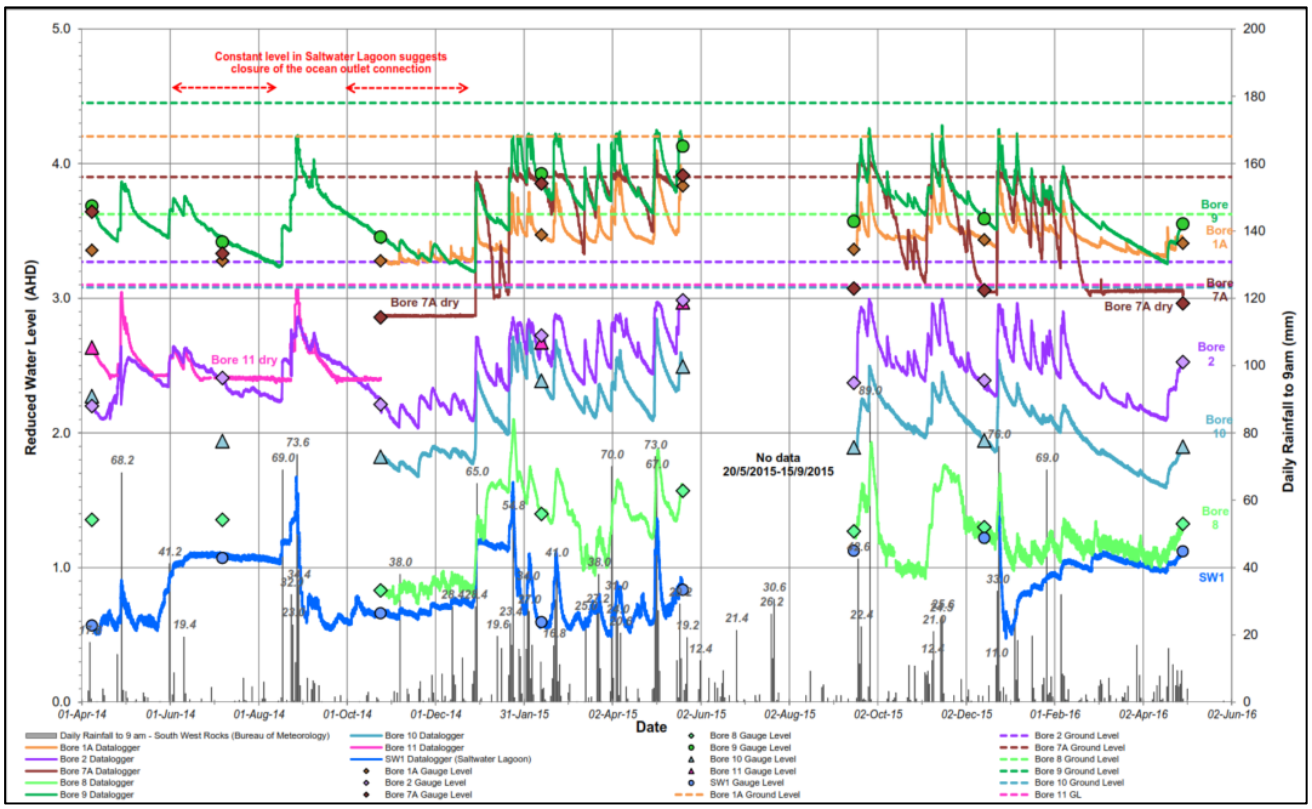

Figure 10: Previous Groundwater Level Monitoring Results April 2014 to June 2016

5.2 Groundwater Management

No details are available regarding the proposed water management arrangement for the current proposed concept plan. The overall footprint of the development is similar to that previously proposed as covered in the 2016 report. Observations at the site on 17 December 2021 were consistent with previous site monitoring results and the concept groundwater model presented in 2016 is considered to remain valid.

Provided that a similar approach to water management is proposed for the new concept design it is considered that the general recommendations from Douglas Partners 2016 report would still apply. This would require a network of surface and subsurface drainage to limit upper groundwater levels as well as downstream infiltration areas to maintain downstream groundwater baseflows to the downstream riparian areas. Some adjustability is recommended for the system, for example adjustable overflow weirs to allow for refinement of the system in the longer term.

Surface water discharges to the downstream area is outside the scope of Douglas Partners current and previous assessments and should be assessed by specialist surface water consultants, taking into account the groundwater management recommendations.

Detailed design will be required to confirm appropriate water management measures and will require surface water modelling as well as detailed numerical groundwater modelling. The groundwater data collected by Douglas Partners in the period 2014 to 2016 is considered to be suitable for calibration of a numerical model, although collection of more recent monitoring data would be beneficial for the robustness of the model. Once the layout of proposed drains and swales is confirmed it would be prudent to undertake additional site investigation to confirm infiltration conditions at the specific proposed swale locations.

Groundwater monitoring should also be undertaken during and following construction to allow ongoing refinement of the design measures and adjustment of weir levels, if required. Monitoring recommendations for Stage 1 of the development were provided in Douglas Partners 2013 report and are still considered appropriate for Stage 1. This will require installation of additional wells in the downstream environmental protection area and ongoing monitoring. The results of this monitoring can then be used to refine the future detailed design for the remaining areas of site.

6. References

DP. (2013). *Report on Groundwater Impact Assessment, Proposed Stage 1 – Saltwater Development, South West Rocks, Project 39787.01 .* Douglas Partners Pty Ltd.

DP. (2016). *Review of Groundwater Management for Concept Plan, South West Rock Groundwater Monitoring, Phillip Drive, South West Rocks, Project 39787.02.* Douglas Partners Pty Ltd.

7. Limitations

Douglas Partners (DP) has prepared this report for this project at Phillip Drive, South West Rocks in accordance with DP's proposal 39787.03.P.001 dated 7 December 2021. The work was carried out under DP's Conditions of Engagement. This report is provided for the exclusive use of SW Rocks Developments Pty Ltd for this project only and for the purposes as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other site or by a third party. Any party so relying upon this report beyond its exclusive use and purpose as stated above, and without the express written consent of DP, does so entirely at its own risk and without recourse to DP for any loss or damage. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

The results provided in the report are indicative of the sub-surface conditions on the site only at the specific sampling and/or testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after DP's field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site between and beyond the sampling and/or testing locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

The assessment of atypical safety hazards arising from this advice is restricted to the groundwater components set out in this report and based on known project conditions and stated design advice and assumptions. While some recommendations for safe controls may be provided, detailed 'safety in design' assessment is outside the current scope of this report and requires additional project data and assessment.

This report must be read in conjunction with all of the attached and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion stated in this report.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

Please contact the undersigned if you have any questions on this matter.

Yours faithfully
Douglas Partners Pty Ltd

Will Wright
Principal

Reviewed by

Michael Gawn
Principal

Attachments: About this Report
2016 Douglas Partners Report

About this Report

November 2020

Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

Copyright

Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

continued next page

Site Anomalies

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

Information for Contractual Purposes

Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection

The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.

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Project 39787.02
4 August 2016
R.002.Rev0
PWW:DEW:kd

Attention: Steve MacDonald

Email: stvnrmacdonald@gmail.com

Dear Sirs

Review of Groundwater Management for Concept Plan
South West Rocks Groundwater Monitoring
Phillip Drive, South West Rocks

1. Introduction

This letter provides a review of the proposed Saltwater Development Concept Plan with regard to management of groundwater infiltration. The work was carried out for S W Rocks Developments Pty Ltd.

The site was the subject of a hydrogeological assessment by Douglas Partners in 2007 (Ref 1) which provided results of a hydrogeological investigation and a qualitative assessment of the proposed development. The report indicated that integrated stormwater and groundwater management should be achievable using a combination of appropriate drainage measures within the development and reinjection of groundwater at the perimeter of the development to mimic pre-development groundwater levels and flows to the wetlands.

The purpose of this review was to provide the following:

- Review of groundwater monitoring data collected at the site;
- Update conceptual groundwater model for the site based on the results of the monitoring;
- Review the proposed concept design;
- An assessment of the concept design with regard to the design of a system to replicate the natural groundwater flows downstream of the development, as required by the DCP, and any specific requirements that would be required to be incorporated into the concept design to ensure that such a system would be feasible subject to detailed design;
- Recommendations for detailed design of the groundwater management system.

2. Saltwater Development Control Plan

A development control plan has been developed for the overall Saltwater development area by Planit Consulting on behalf of Kempsey Shire Council (Ref 2).

The DCP include the following requirements:

- "Ensure there are no changes to the natural groundwater regime that could adversely affect Saltwater Lagoon and Creek by either reducing the volume of flow behind the natural rate, by reducing the area available for infiltration and recharging and increasing the pollutant load above natural levels";
- "Ensure that there remains after development a balance between the surface and groundwater flows that mimic the natural condition through operation, implementation, review and maintenance of a suitable detailed Water Management System developed prior to finalising any development proposal."

3. Rainfall Recharge

Only a certain percentage of rainfall that falls on a site will result in recharge to groundwater, the remainder will be accounted for by surface runoff and evaporation. Evaporation occurs to water before it has a chance to infiltrate to groundwater and evapotranspiration losses (evaporation assisted by transpiration of plants) can also occur directly from groundwater, with the effects greater the shallower the groundwater and with vegetation present. Net recharge is a term that is used to represent the effective recharge which occurs to an aquifer taking into account subsequent evaporative losses and is generally substantially less than the gross recharge, which is the amount of water that initially reaches the water table from rainfall events.

The relative percentages of runoff, recharge and evaporation that occur can vary greatly from site to site depending on particular site characteristics including site slopes, soil permeability, depth to water table and vegetation.

In order to provide a likely range of net infiltration rates for the subject site, comparison has been made to other similar coastal sandy sites as follows:

- Tomago Sandbeds is a coastal sandy site located to the north of Newcastle. The depth to the water table is near the surface in places but is generally several metres deep and generally deeper than the South West Rocks site. Research by Viswanathan (Ref 6) indicted a gross recharge of 52%. Modelling by Douglas Partners and others has indicated net recharge rates in the range 10% to 30% of rainfall (Ref 5).
- Nabiac Water Supply. A calibrated model was developed to assess water supply sustainability in this sandy aquifer. The modelling indicated a gross recharge rate of 55% with a net recharge rate of 20% to 30% (Ref 4).
- Great Keppell Island: A calibrated model for the sandy aquifer indicated a gross recharge rate of about 55% (Ref 3)

Therefore for a range of coastal sandy aquifers gross recharges of about 50 to 60% are typical with net recharges in the range 20 to 40 %, depending on particular site characteristics. The subject site has its own characteristics which will affect the recharge, runoff and evapotranspiration processes and a conceptual model has been developed to consider these characteristics and their effect on net recharge.

4. Climatic Records

Information from the Bureau of Meteorology for the site indicates that the nearest weather station to the site is Smoky Cape, about 4 km to the south-west of the site. The average annual rainfall is 1491 mm per year and although no pan evaporation data is available for Smokey Cape, reference to contours of pan evaporation published by the Bureau of Meteorology indicate average yearly pan evaporation is in the range 1000 to 1200 mm per year for the region.

The rainfall data from Smoky Cape for the period 1939 to 2013 has been analysed with respect to how much contribution to the overall magnitude of rainfall is made from daily events of different sizes. Figure 1 below presents the individual and cumulative percentage contribution to overall rainfall of different ranges of daily rainfall amount.

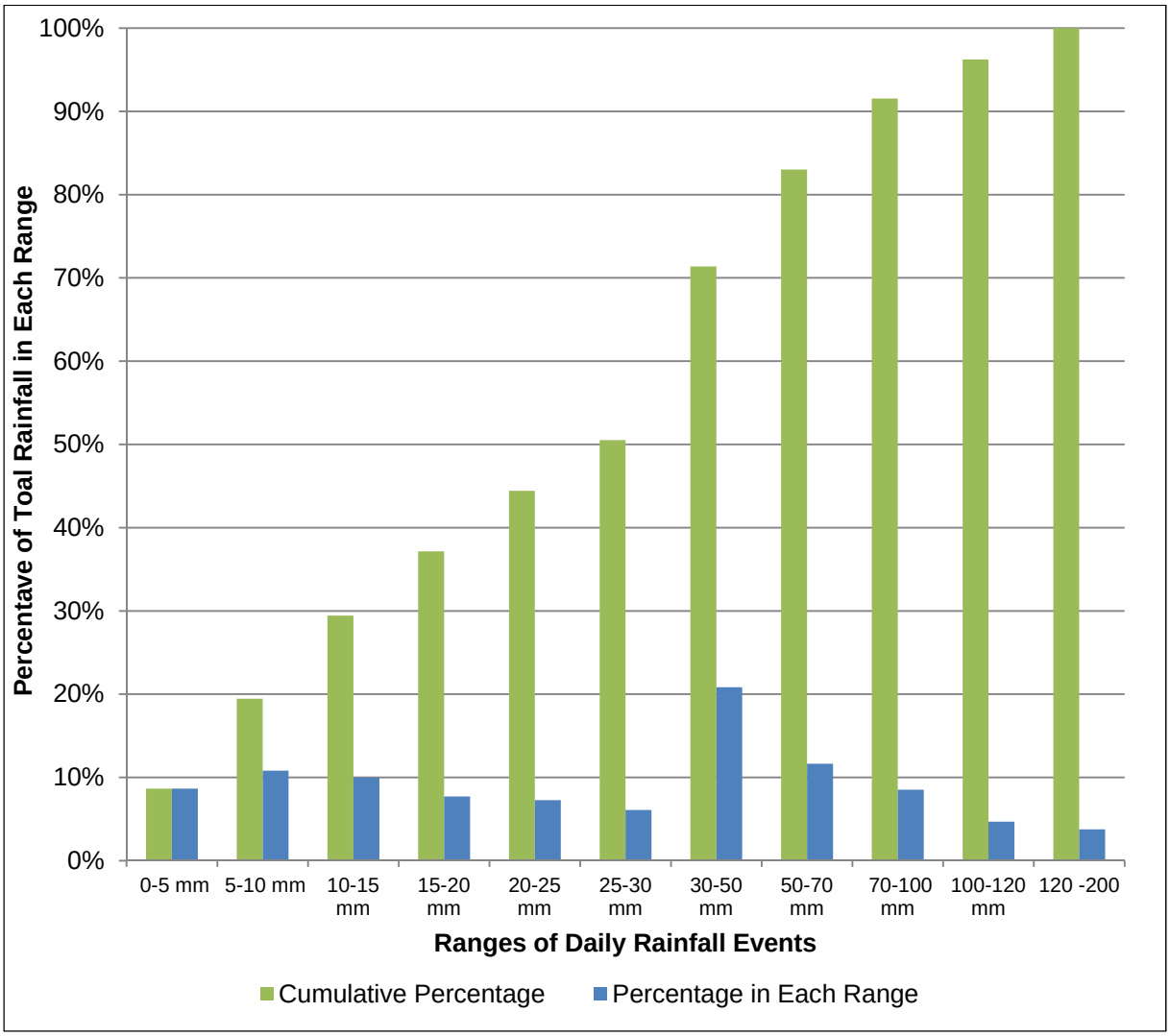


Figure 1: Analyses of Rainfall Distribution

Figure 1 above indicates that despite rainfall events of less than 5 mm being quite common they account for less than 10% of the rainfall amount at the site. 30% of the rainfall amount occurs for events of less than 15 mm and only 17% of the rainfall amount occurs for event of 70 mm or more.

5. Review of Groundwater Monitoring

Monitoring of groundwater levels has been undertaken at the site at seven well locations spread across the overall development site for the period April 2014 to June 2016 and is ongoing. The monitoring locations are shown on Figure 2, which also shows the overall proposed extent of development. The results of monitoring are presented on Figure 5 attached.

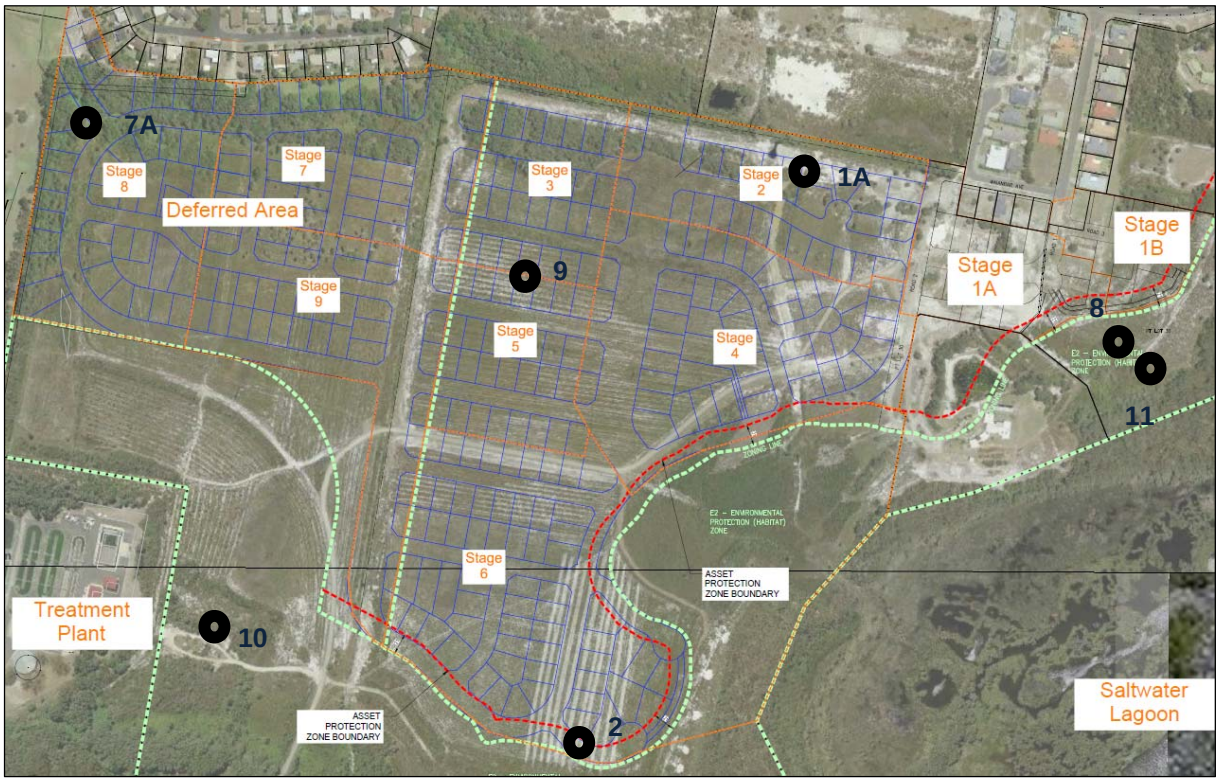


Figure 2: Proposed Development Site and Groundwater Monitoring Locations

A semi quantitative analysis has been undertaken to assess the variations in groundwater levels with variations in rainfall conditions in order to provide some qualitative detail to the conceptual model developed for the site.

It is noted that the rainfall records used for assessing the trends in groundwater levels are from Smoky Cape about 4 km to the south east of the site. The rainfall records are expected to provide an indication of the rainfall falling on the site however due to spatial variations in rainfall individual rainfall events may not be representative. An example of this is a rainfall event of 38 mm which occurred in November 2014 at Smoky Cape for which no groundwater responses were observed on the site, indicating that this rainfall event probably missed the site.

Overall the monitoring is consistent with the shape of the contours and inferred groundwater flow directions as presented on Drawing 1 of DP's report 39787.00 of September 2007. Figure 3 was a snapshot of the water levels on 24 July 2007 and the results of monitoring indicated that the water levels at this snapshot were in the lower half of the range of observed water levels since April 2014.

The groundwater levels show reasonably good correlation with rainfall, with relatively sharp increases in groundwater levels following rainfall events and steady recession in groundwater levels between rainfall events. The amount of rainfall response is generally less when the preceding conditions have been relatively dry and the water table is relatively low and higher for shallower groundwater depths.

It is also clear that at some locations, mostly Bores 1A, 7A and 9 located on the northern parts of the site, the water table regularly hits a ceiling level at which no more increase in groundwater levels occurs for increasing rainfall events. The ceiling levels are considered to occur due to the influence of the ground surface features leading to surface drainage of the groundwater, thereby creating an effective maximum groundwater level, which is generally close to or at the ground surface. The data has been interrogated to assess what range of daily rainfall events is required to raise the water table to the ceiling levels and the results are summarised in Table 1.

Table 1: Summary of Groundwater Levels in Wells on Northern Parts of Site

Bore	Surface Level (AHD)	Observed Range of Groundwater Level/Depth		Average Groundwater Level/depth		Typical Ceiling Level		Typical Range of Rainfall for Ceiling Level (mm)
		Level (AHD)	Depth (m)	Level (AHD)	Depth (m)	Level (AHD)	Depth (m)	
1A	4.2	3.3 to 4.1	0.1 to 0.9	3.4	0.8	3.9	0.3	40 to 50
7A	3.9	<3.1 to 4.0	0 to >0.8	3.5	0.45	3.9	At surface	20 to 30
9	4.45	3.2 to 4.2	0.25 to 1.25	3.7	0.8	4.2	0.25	30 to 40

Bores 2, 8, 10 and 11 are located along the downstream fringes of the proposed development in the general vicinity of where infiltration of groundwater is proposed. The depth to groundwater is generally deeper than the northern locations with ceiling levels only occurring occasionally and at greater depth. One exception to this is Bore 11 which was installed above a localised low permeability layer which leads to perching of the water table and highly responsive groundwater. Bore 8 is located upstream, away from the influence of the perching layer and shows a deeper and less responsive water table. The results of the monitoring are summarised in Table 2

Table 2: Summary of Groundwater Levels in Wells on Southern and Eastern Parts of Site

Bore	Surface Level (AHD)	Observed Range of Groundwater Level/Depth		Average Groundwater Level/depth		Typical Ceiling Level		Typical Range of Rainfall for Ceiling Level (mm)
		Level (AHD)	Depth (m)	Level (AHD)	Depth (m)	Level (AHD)	Depth (m)	
2	3.3	2.0 to 3.0	0.3 to 1.3	2.5	0.8	2.9	0.4	30 to 70
8	3.6	0.8 to 2.1	1.5 to 2.8	1.2	2.4	NA	NA	NA
10	3.1	1.7 to 2.9	0.2 to 1.4	2.1	1.0	NA	NA	NA
11	3.1	<2.4 to 3.1	0 to >0.7	2.5	0.6	3.1	0	30 to 40

Lagoon levels were observed to typically range from about RL 0.5 to 1.2 AHD. Higher water levels occurred for short periods following large rainfall events with peaks of up to RL 1.7. The level of 1.1 to 1.2 AHD seems to have been a medium to long term ceiling level and is likely controlled by the level of the outlet at the beach.

6. Conceptual Hydrogeological Model

A conceptual hydrogeological model was developed for the site in 2007 (Ref 1). The model has been updated to a semi quantitative model based on the results of groundwater modelling, background information on recharge and analyses of the long term rainfall records for the site.

The groundwater contours prepared in 2007, as shown in Figure 3 are considered to provide a reasonable representation of groundwater flow directions on the site, albeit in the lower end of the range of water levels. Groundwater generally flows from the site, radially outwards towards the creek to the south and the lagoon to the east. The groundwater flows are driven by direct rainfall recharge on the site.

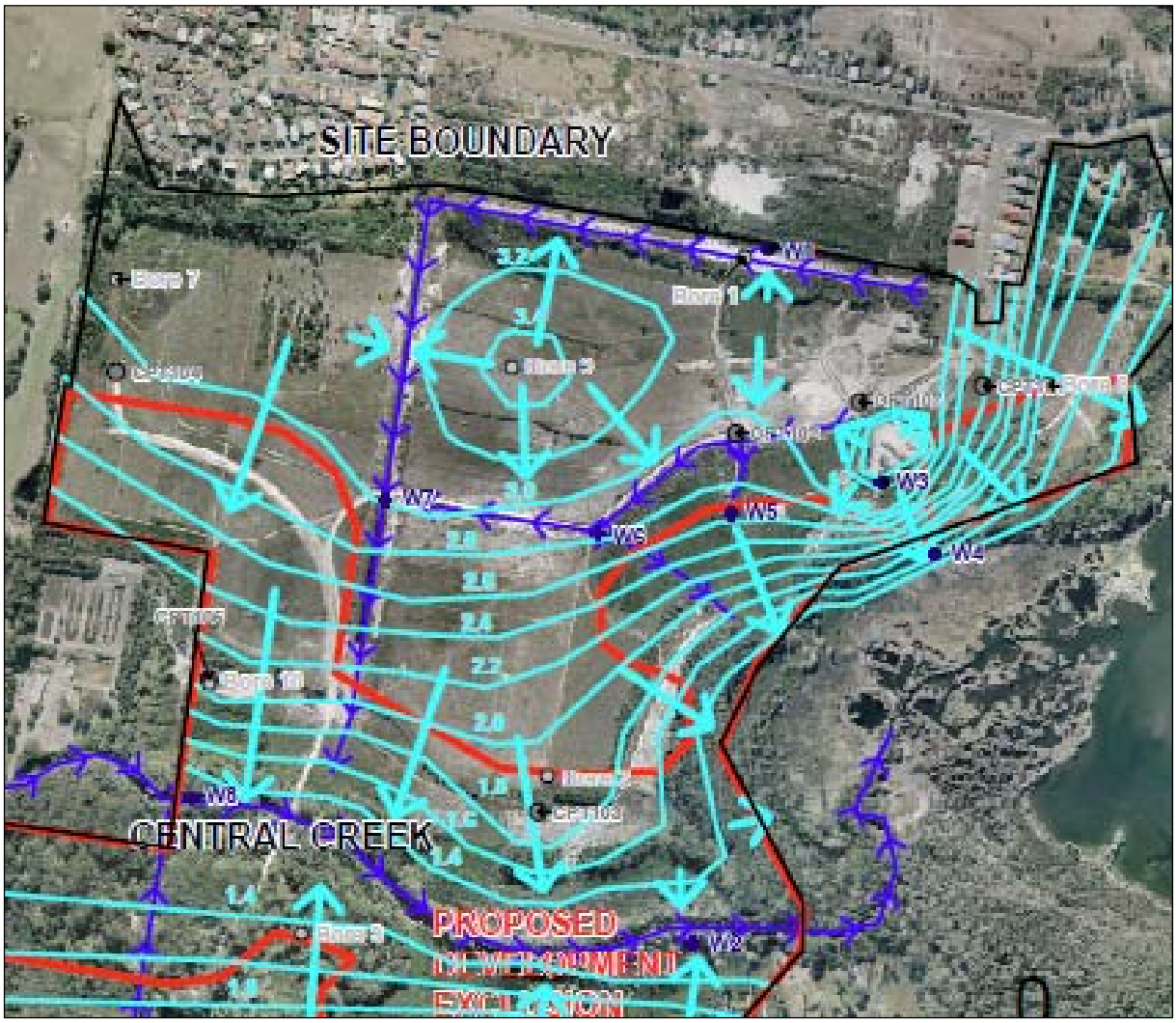


Figure 3: Groundwater Contours from July 2007

The ground surface is low lying, typically RL 3.5 to 4.5 AHD and also contains various shallow drainage trenches and features which will locally influence groundwater flow directions as well as provide an upper limit on groundwater levels within the site;

Groundwater levels are transient and vary with rainfall. Levels typically range from about RL 3.0 to 4.2 AHD on the northern parts of the site to about RL 0.8 to 3.1 on the downstream southern and eastern fringes of the proposed development.

In times of lower groundwater levels, which can occur during dry climatic conditions the surface drainage features have little impact on the groundwater flows. For larger rainfall events the ground becomes saturated and/or controlled by surface drainage and above a certain threshold rainfall, all subsequent rainfall becomes surface runoff, flowing to the lagoon by overland flow and through the various drainage channels The monitoring data indicates the threshold rainfall events are typically about 20 mm to 50 mm, less in the north west corner of the site and greater along the downstream fringes of proposed development.

For very small rainfall events, less than about 5 mm rainfall recharge is expected to be very limited with most rainfall lost due to evaporation before it reaches the water table. Groundwater responses to rainfall were generally only observed for rainfall events of about 10 mm or more.

When the rainfall analyses on Figure 1 is considered it can be seen that rainfall associated with events of less than 5 mm account for about 10% of total rainfall. Similarly rainfall events up to say 35 mm (the typical ceiling value for rainfall recharge) relate to slightly more than 50% of total rainfall. Overall the analyses suggests that the gross recharge to the site is likely to be about 40 to 50% of annual rainfall. This is slightly less than observed on other sandy coastal aquifers, however none of the other aquifers discussed in Section 3.0 have the same low-lying characteristics that lead to additional surface runoff components.

As the site is low lying with groundwater levels generally within 2 m of the ground surface or less, the effects of evapotranspiration are expected to be significant. Evapotranspiration is complex and depends on the depth of water, however for groundwater modelling purposes is typically simplified by adopting a maximum of about 70% of pan evaporation at the surface, linearly decreasing with an extinction depth of about 2 m. Based on a lower-bound pan evaporation rate of 1000 mm per year, the annual average rainfall of 1491 mm and an average groundwater depth across the site of about 1 m, this equates to about 350 mm of evapotranspiration per year, which is 24% of the annual rainfall. Taking this into account a gross recharge rate of 50% would relate to a net recharge rate of about 25%. This is within the range expected for a coastal sandy aquifer.

7. Proposed Stormwater Management

Based on the Stormwater Management Plan developed by de Groot & Benson Pty Ltd the stormwater management system is to comprise the following elements as shown on Figure 4:

- The overall development area is 33 Ha and about 50% of the developed area is to be impervious area comprising roads, paving and roofs, the remainder of the site will remain pervious;
- Stormwater is proposed to be collected by conventional kerb and guttering with conventional kerb inlets pits and piped road drainage plus piped inter-allotment drainage where lots do not fall to the street;
- Due to limited site grades the pipes will discharge into lined swales;
- The swales are to discharge into unlined infiltration beds located on the downstream edges of the development in accordance with the general strategy proposed in DP's report of 2007 (Ref 1);
- Subsoil drainage will be included within the development to control upper bound groundwater levels, also suggested in DP's report of 2007 (Ref 1);
- Filling of the site is expected to be required to provide a minimum of 1 m clearance to groundwater levels.

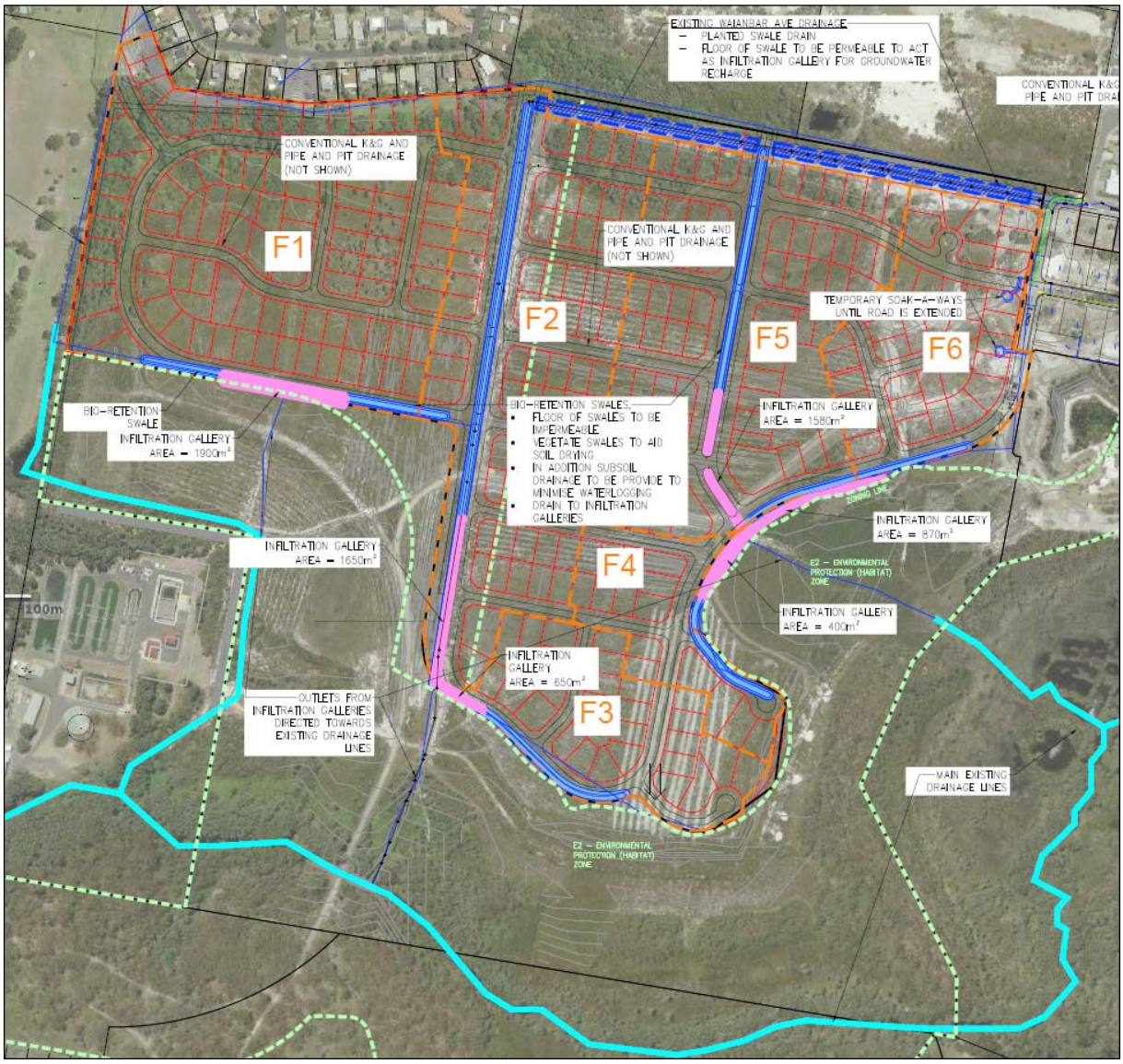


Figure 4: Concept Design for Stormwater Management

8. Potential Impacts of Development on Groundwater

Pervious areas such as road, paving and house footprints will prevent direct recharge and evapotranspiration below their footprints. The effect will be a reduction in the net recharge below the development site of about 50%. In order to maintain similar groundwater flows downstream of the development it will be necessary to reintroduce a similar volume of collected stormwater via the infiltration beds on the downstream boundaries of the site.

As outlined in the conceptual groundwater model the estimated net research to the site is about 25% of total rainfall and reference to the rainfall analyses presented on Figure 1 indicates that rainfall events of up to 15 mm account for 25% of rainfall. Therefore adequate infiltration could be achieved by collecting and infiltrating rainfall events of up to about 15 mm, with excess flow discharged overland.

The groundwater levels vary with time. Average groundwater depths over time at the bores range from 0.45 m (Bore 7A) to 2.4 m (Bore 8) and for most bores the depths are between 0.5 m and 1.0 m most of the time. Shallow groundwater at less than 0.5 m depth occurs most commonly on the northern parts of the site.

The overall impact on groundwater levels below the site due to the pervious areas and infiltration on the downstream boundaries will likely be some mounding of water levels around the infiltration areas with a flatter gradient below the site and lower groundwater levels on the northern parts of the site. Given the water levels on the northern parts of the site are about 1 m higher than the levels on the downstream parts of the development site then a 50% reduction in net recharge over the development site may lead to up to about a 0.5 m reduction in water levels at the northern end of the site, probably a little less accounting for upstream inflows and less limiting of rainfall recharge due to surface effects.

In the vicinity of the proposed infiltration areas the minimum recorded water depths are in the range 0.2 m to 1.5 m and therefore the ground can generally be expected to have the capacity to accept infiltration of rainfall events of up to about 15 to 20 mm provided sufficient grades are available to allow the head of water in the infiltration area to be above the groundwater level and sufficient area is available to spread the infiltration and reduce mounding. Orientation of the infiltration trenches parallel to the groundwater flow i.e. parallel to the downstream boundary of the site will reduce mounding. In some locations confining layers are present which may impede vertical infiltration and it may be necessary to penetrate these layers to allow vertical distribution of the infiltrated water.

Taking into account the potential for some reduction in groundwater levels on the northern parts of the site, if a target minimum depth to groundwater of 1.0 m is to be achieved for the developed site there will still be a need for raising/filling of the site and/or installation of subsurface drainage to limit groundwater levels.

Filling of the site has the potential to allow higher groundwater levels to occur at times of wet weather if the existing surface drainage controls are affected by any filling. Similarly if the proposed swales are to be lined then this may also nullify the effect of any existing drainage controls, increasing water levels. Therefore it is considered that subsoil drainage will need to be incorporated into the development. For subsoil drainage installed at the measured ceiling groundwater levels this would restrict groundwater levels within the existing range of levels across the site. Depending on the amount of site raising it may be necessary to further limit the upper groundwater level by installing deeper subsoil drainage. Given that the groundwater levels below the site are predicted to drop slightly due to the impervious surfaces, some deepening of the subsoil drainage will have very limited adverse effects. However at some point (less than 0.5 m depth), deeper drainage will affect the groundwater flows downstream of the site. It is expected that this can be compensated for by allowing for some additional infiltration by allowing capture of slightly larger rainfall events for infiltration at the downstream boundary of the site.

9. Detailed Design Requirements

It is considered that the site can be developed in a manner which can provide a reasonable replication of existing groundwater flows downstream of the site. Exact replication of the natural system is not a practical expectation of such an artificial system, however subject to appropriate detailed design, on-going groundwater monitoring and with flexibility in the design to allow for some adjustment of weir overflow levels, it is anticipated that the impacts are expected to fall within typical seasonal variations in groundwater flow and levels.

Detailed design will be required to refine the balance required between the size and level of infiltration areas, the amount of site filling and the level of subsurface drainage. The above preliminary analyses suggest that the design should be feasible with filling of up to about 0.5 m in places and/or installation of subsoil drainage to depths of 0.5 m to 1.0 m together with the capacity to store daily rainfall events of up to about 15 to 20 mm for infiltration. The infiltration areas should ideally be oriented longitudinally along the downstream boundaries of the site and should be designed to allow adjustment of the overflow levels.

Detailed design will require surface water modelling and the development of a numerical groundwater model. The groundwater model should be calibrated to replicate groundwater monitoring data. Simulation of the proposed development will then be required. In order to provide a satisfactory estimate of infiltration storage requirements the modelling will need to include transient analyses using daily time steps.

10. References

1. Douglas Partners, “Report on Hydrogeological Assessment, Proposed Residential Subdivision, Off Phillip Drive, South West Rocks”, 39787, October 2007.
2. Planit Consulting., “Saltwater South West Rocks Development Control Plan” September 2010.
3. Douglas Partners, “Report on Groundwater Supply Investigation, Great Keppel Island”, 33976, February 2007
4. Douglas Partners, “Report on Phase Two Groundwater Modelling of Nabiac Aquifer”, 21965C, October 2002
5. Douglas Partners, “Report on Groundwater Impact Assessment, Proposed Industrial Subdivision, Off Old Punt Road, Tomago, New South Wales”, 81498.02, May 2014.
6. Viswanathan, “Recharge Characteristics of and Unconfined Aquifer from the Rainfall –Water Table Relationship”, Journal of Hydrology, 70 (1984).

11. Limitations

Douglas Partners (DP) has prepared this report (or services) for this project at Phillip Drive, South West Rocks at the request of Steve MacDonald of SW Rocks Developments Pty Ltd. The work was carried out under DP's Conditions of Engagement

With the exception of the parties listed below this report is provided for the exclusive use of S W Rocks Developments Pty Ltd, TeeBee property Trust, De Groot & Benson Consulting Engineers Geoff Smyth Consulting and Keiley Hunter Urban for this project only and for the purposes as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other site or by a third party. Any party so relying upon this report beyond its exclusive use and purpose as stated above, and without the express written consent of DP, does so entirely at its own risk and without recourse to DP for any loss or damage. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

The results provided in the report are indicative of the sub-surface conditions on the site only at the specific sampling and/or testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of human influences. Such changes may occur after DP's field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be affected by undetected variations in ground conditions across the site between and beyond the sampling and/or testing locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

This report must be read in conjunction with all of the attached and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion stated in this report.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

Please contact the undersigned if you have any questions on this matter.

Yours faithfully
Douglas Partners Pty Ltd

Will Wright
Principal

Reviewed by

Stephen Jones
Principal

Attachments: About this Report
Figure 5: Groundwater and Surface Water Levels vs Rainfall (Ref 4)

About this Report

Douglas Partners

Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

Copyright

Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

About this Report

Site Anomalies

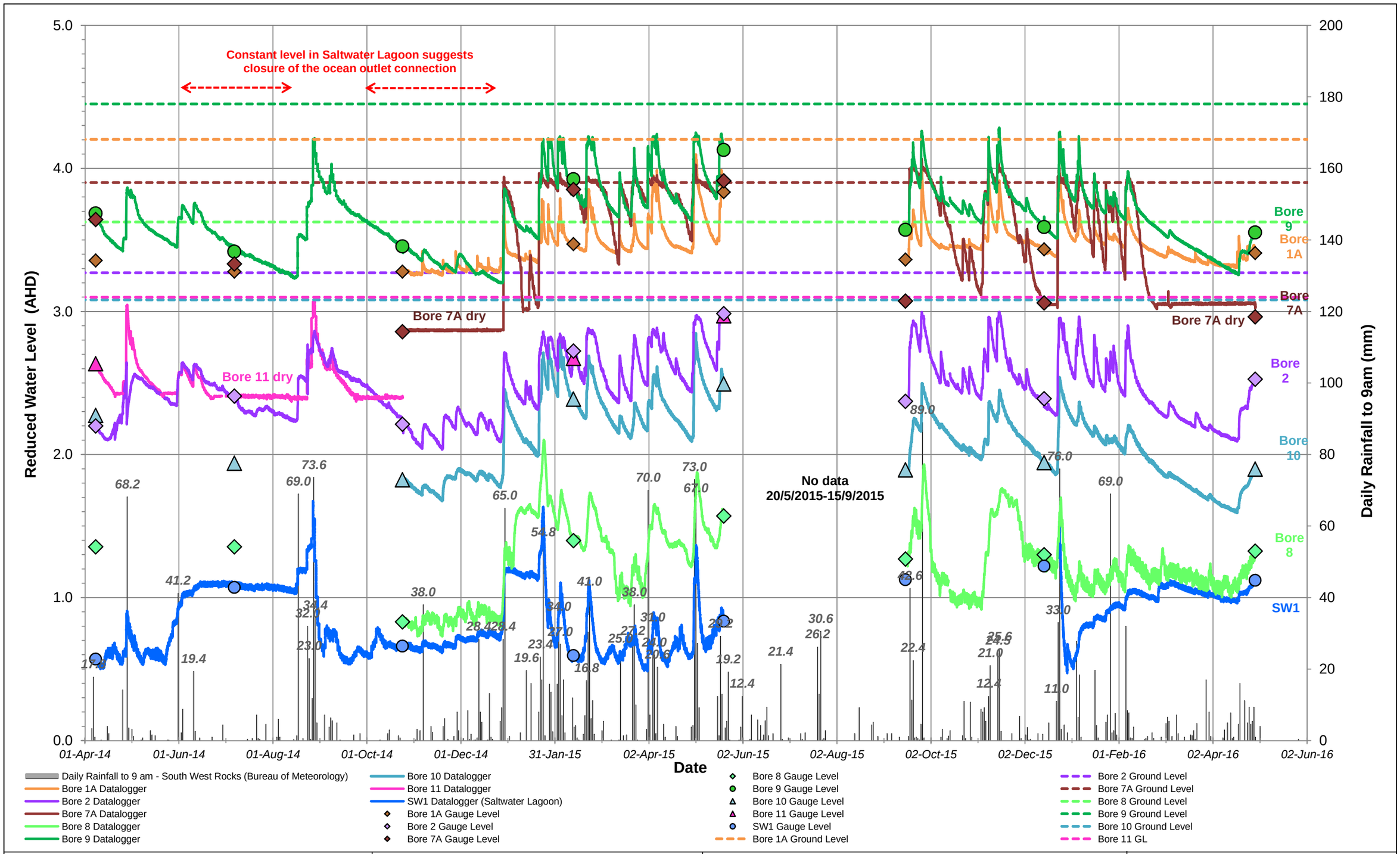
In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

Information for Contractual Purposes

Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection

The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.



Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: S W Rocks Developments Pty Ltd	TITLE: **Groundwater and Surface Water Levels vs Rainfall** **Proposed Residential Subdivision** **Phillip Drive, South West Rocks**	PROJECT NO: 39787.02
	OFFICE: Newcastle / DRAWN BY: DEW		FIGURE NO: 5
	SCALE: N/A / DATE: 13.07.2016		REVISION: 4