Groundwater Monitoring Program

Googong Township Integrated Water Cycle Project

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Terms and Abbreviations

3D	Three dimensional
BOD	Biological oxygen demand
BOM	Bureau of Meteorology
Ca	Calcium
Cl	Chloride
CoA	Condition of Approval
CoC	Chain of Custody
CO_3	Carbonate
CRMRM	Cumulative residual monthly rainfall mass
EC	Electrical conductivity
EPA	Environment Protection Authority
Fe	Iron
FEM	Frequency domain electromagnetic measurements
GPS	Global Positioning System
GTPL	Googong Township Proprietary Limited
GWMP	Groundwater Monitoring Program
HCM	Hydrogeological conceptual model
$H\ CO_3$	Bicarbonate
IWC	Integrated water cycle
mAHD	Metres above height datum
mbgl	Metres below ground level
Mg	Magnesium
mg/L	Milligrams per litre
Na	Sodium
NATA	National Association of Testing Authorities
NEPM	*National Environment Protection (Assessment of Site Contamination) Measure 1999*
NH1A	Neighbourhood 1A
NOW	NSW Office of Water
NSW	New South Wales
OEH	NSW Office of Environment and Heritage
Operator	GTPL (during process commissioning and verification) or QCC (during ongoing operation)
QCC	Queanbeyan City Council
Program	Groundwater Monitoring Program

PVC	polyvinyl chloride
SO_4	Sulphate
SoC	Statement of Commitments
SWAEMP	Surface Water (and Aquatic Ecology) Monitoring Program
TDS	Total dissolved solids
TKN	Total Kjeldahl Nitrogen
TSS	Total suspended solids
WMP	Water Management Plan
WRP	Water Recycling Plant
µg/L	Micrograms per litre
µS/cm	MicroSiemens per centimetre

B1 Purpose

This Groundwater Monitoring Program (GWMP or the 'Program') has been prepared to satisfy Condition of Approval (CoA) D8 (b) for Stage 1 of the Googong Township Integrated Water Cycle (IWC) Project with interfaces to the other sub-plans of the Water Management Plan (WMP), where necessary (refer to Table 1 and Table 2).

It is intended that this document be a practical and adaptable guideline that sets out groundwater monitoring requirements – including location, methodology, and timing for the IWC Project. Results of the monitoring program will be considered in the context of the WMP to determine impacts to groundwater and appropriate responses to address any exceedances of trigger levels.

Table 1 Conditions of Approval

CoA No.	Requirement	Reference/ Comments
D8	The Proponent shall prepare and implement a Water Management Plan for the project to manage potential impacts on surface water and groundwater systems during operation of the project. The plan must be prepared in accordance with Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC & ARMCANZ, 2000), particularly Volume 1, Chapter 5: Guidelines for Recreational Water Quality and Aesthetics and Volume 2, section 8.2.3: Aquatic Ecosystems, and include:	This Program forms an appendix to the WMP.
	1. a **Groundwater Monitoring Program**, including:	This Program
	A. detailed baseline data of groundwater levels, yield and quality in the region, and privately-owned groundwater bores, that could be affected by the project;	Section B2 and WMP Section 4.1.2
	B. groundwater impact assessment criteria including trigger levels for investigating any potentially adverse groundwater impacts;	Section B4
	C. a program to monitor and assess: (a) impacts on the groundwater supply of potentially affected landowners; (b) impacts on any groundwater dependent ecosystems and riparian vegetation;	Sections B3 and B5 WMP Appendix A
	The Water Management Plan and sub-plans shall be prepared in consultation with OEH, NOW, NSW Health and DTIRIS (Fisheries), and be submitted to the Director-General for approval by the end of June 2012 and prior to commencing operation of the project, unless otherwise agreed by the Director-General.	WMP Section 1.4

Table 2 Statement of Commitments

Objective	Ref. No.	Commitment	Document reference
Ensure comprehensive monitoring of operation of the water cycle	OP1	Establishment and location details for monitoring sites will be in accordance with WQ4. Results of all monitoring programs that form part of these Statement of Commitments will be considered in terms of overall environmental impact on a regular basis, including: ▪ The trade-off between potable water savings, reduction in stormwater discharges and increased recycled water discharges. ▪ Relative impacts of excess recycled water discharges compared to impacts on soil and groundwater from recycled water uses. ▪ The timeframe for relative comparisons of impacts components of the water cycle will be determined in consultation with the relevant government agencies. ▪ The ability to feedback results for further stages of Googong township.	Section B2
Ensure minimal impact on soil salinity and groundwater quality	S5[1]	Early stages of Googong township will be used as a trial to better understand the movement of salt in the landscape. It will involve the installation of carefully located piezometers and the monitoring of results, as well as monitoring the effectiveness of pre-emptive measures such as any subsurface drainage system. The results will be used to improve strategies for ensuing stages.	Section B2, WMP Section 4.1.2 and Appendix E
Monitor groundwater quality to avoid adverse impacts	G3	Develop a groundwater monitoring program for the Project in consultation with relevant stakeholders. The program will address the following: ▪ The salt levels in groundwater will be regularly monitored during and after Stage 1 of the Project. ▪ Groundwater samples will be collected from both the shallow and regional aquifers, and soil conductivity (that is, salt) mapping will be carried out where possible in areas of inferred impact. ▪ The monitoring of salt levels in the receiving waters will be indicative of the effectiveness of the stormwater system.	Sections B2 and B5, WMP Section 4.1.2 and Appendix E
Minimise salinity impacts on soil and plant growth	G7	Soil monitoring in low-lying areas, where salt is likely to accumulate, will be undertaken. If salt levels were shown to be increasing, engineered drainage structures to nearby creek lines will be constructed. As a preventative measure, to avoid future bare soil patches and erosion, salt-tolerant landscaping will be used in low-lying areas.	WMP Appendix E

[1]Other components of SoC S5 not relating to operation have not been included, as they have been captured in other stages or documents.

Objective	Ref. No.	Commitment	Document reference
Further investigate the groundwater environment, potential changes to recharge, and likelihood of long-term impacts	G8	Undertake the groundwater monitoring program as outlined in Table 12 of this report[2].	This Program

[2] *"Table 12: Recommended scope of works and timing for future groundwater monitoring program" was included in the submissions reports.*

B2 Baseline monitoring

Baseline groundwater monitoring was completed by SMEC from September 2013 to September 2014 (SMEC 2015a). Construction activity was occurring within the Googong Township throughout the baseline monitoring period. This activity was related to both the IWC Project and residential development works.

B2.1 Monitoring network design

B2.1.1 Program rationale

Monitoring of groundwater levels, quality and hydrogeological characteristics is being carried out within the IWC Project area following the establishment of a new set of monitoring bores. New bores are required due to the absence of bores within the IWC Project area and the extensive land forming undertaken during the development of the Googong Township.

For Stage 1 of the IWC Project, only boreholes located within Neighbourhood 1A (NH1A) have been constructed (the initial stage of Googong Township) as this will be in areas where land forming has been completed. An additional monitoring well has also been established outside of NH1A (GGW06) to monitor background water quality and water levels in an area unlikely to be impacted by the development. The establishment of further monitoring bores will be undertaken progressively as the township develops, subject to further assessment and approval. It is proposed that in a later phase of investigations the location and behaviour of the inferred groundwater divide with the Googong Dam catchment will be examined.

A total of 11 bore holes have been established as part of the baseline investigations (ranging in depths from three to 55 metres). The location of the monitoring bores are shown in Figure 1. All monitoring bores have been installed firstly to establish baseline groundwater conditions on the site. The bores will then be used for long-term monitoring during the operational phases to monitor key indicators (such as salt levels) and assess any changes from the observed background conditions that may indicate an impact to the groundwater system as a result of operation of the IWC Project.

Details of each bore are described in Table 3.

In addition to the new monitoring bores, monitoring of a number of private bores may occur during operation if bore owners provide permission and the bores are considered suitable. It is recognised that in many cases, especially where the bores are used for stock/domestic purposes, there are existing pumps and headworks that may prevent level monitoring. The locations of four registered private bores, which are of interest as they are down-gradient of monitoring points, are shown in Figure 1.

B2.1.2 Groundwater licence

The NSW Office of Water (NOW) advised that the construction of monitoring bores is an aquifer interference activity under the *Water Management Act 2000*. As provisions of the Act relating to Aquifer Interference approvals have not commenced, a Part 5 licence under the *Water Act 1912* was required for this activity. The NOW issued a Part 5 groundwater licence to Googong Township Pty Ltd (GTPL) on 5 August 2013 for the sinking of monitoring bores. The licence number is 40BL192616.

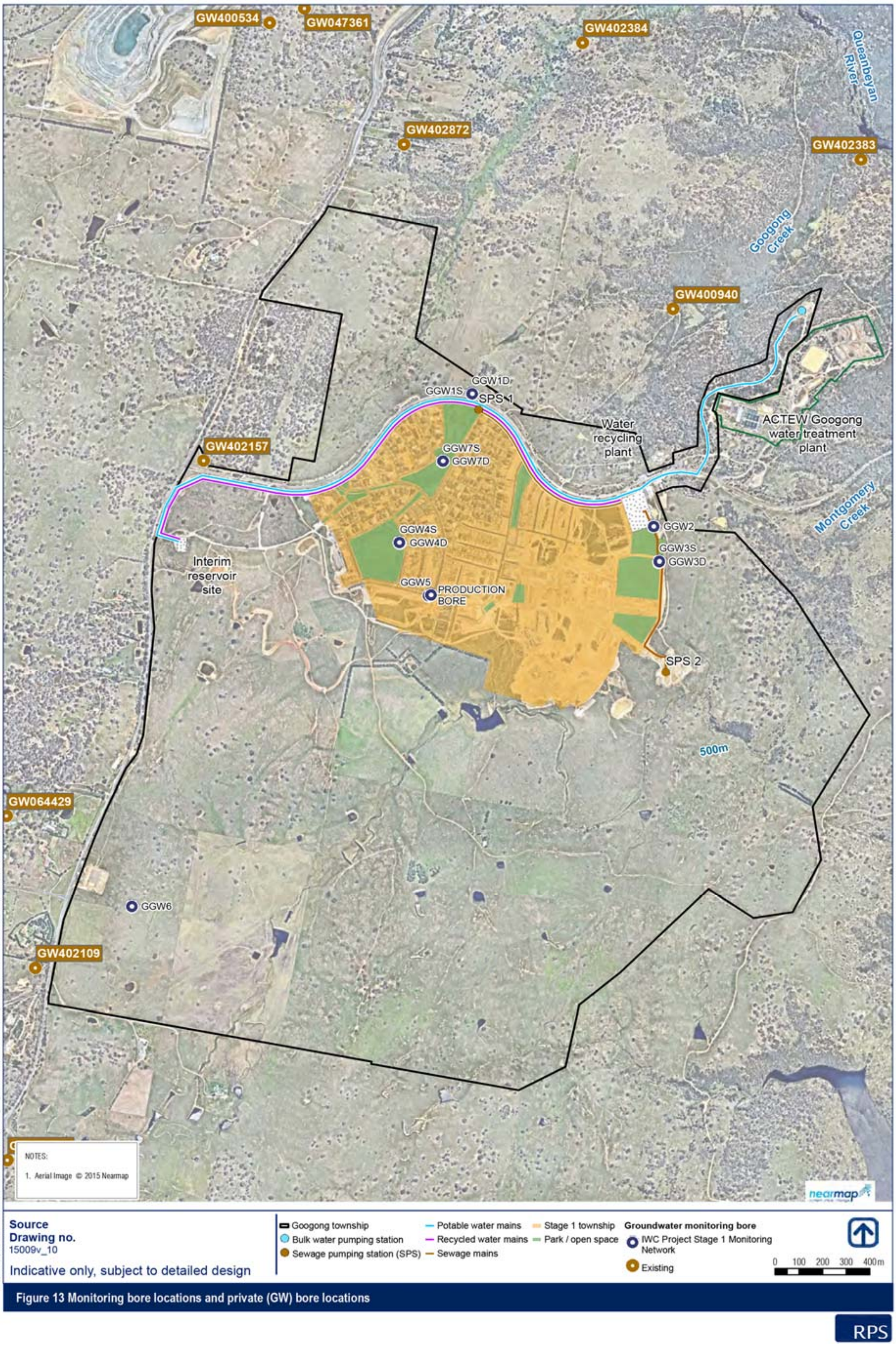

Figure 1 Monitoring bore locations and private (GW) bore locations

Table 3 Details of groundwater monitoring bores

Bore identifier	Total depth drilled (m)	Description of location	RL Top PVC casing (mAHD)	Borehole diameter (mm)	Reason for selection
GGW01s (shallow)	10.5	Immediately north of Googong Dam Road and Beltana Pond irrigation area	724.12	120	Location is down-gradient of much of the proposed Neighbourhood 1A and in particular the Neighbourhood 1A irrigation area, near Googong Creek and is accessible from Googong Dam Road. Bore is screened limestone and shall. Key bore for monitoring salt conditions beneath irrigation area and down-gradient of Beltana Pond.
GGW01d (deep)	19	Immediately north of Googong Dam Road and Beltana Pond irrigation area	723.88	120	Location approximately 10 m from GGW01s. Bore is screened within limestone and shale of the Colinton Volcanics to sample regional water level and quality, and will be useful for monitoring interactions between irrigation area and deeper groundwater.
GGW02	8	South-eastern corner of water recycling plant, within future drainage reserve	720.77	120	Location is accessible from Googong Dam Road, and is designed to monitor shallow groundwater quality up-gradient of the sports-field irrigation areas just south of the water recycling plant. Bore is screened in the weathered Googong Adamellite and underlying Colinton Volcanics dacite.
GGW03s	7	North-eastern corner of second sports field and irrigation area	720.60	120	Location is down-gradient of part of the Neighbourhood 1A, near Googong Creek and accessible from Googong Dam Road. Bore is screened in weathered Googong Adamellite to sample perched water levels, behaviour and quality. Key bore for monitoring salt conditions beneath irrigation area.
GGW03d	25.6	North-eastern corner of second sports field and irrigation area	721.31	120	Location approximately 10 m from GGW03s. Bore is screened within dacite of the Colinton Volcanics to sample regional water level and quality, and will be useful for monitoring interactions between irrigation area and deeper groundwater.
GGW04s	7	North-eastern edge of first recreational reserve and irrigation area	739.40	120	Location is in central part of NH1A, accessible from internal road and downstream of a sports field irrigation area. Bore is screened in weathered shale to sample perched water levels, behaviour and quality. Key bore for monitoring salt conditions beneath irrigation area.

Bore identifier	Total depth drilled (m)	Description of location	RL Top PVC casing (mAHD)	Borehole diameter (mm)	Reason for selection
GGW04d	55	North-eastern edge of first recreational reserve and irrigation area	739.26	120	In central part of NH1A, accessible from internal road. Bore is screened in weathered shale. Objective is to monitor regional aquifer water levels and groundwater quality in mid-region between ridge and creek to assess impacts of post-development groundwater recharge.
GGW05	43	Near top of ridge between Googong and Montgomery creeks	742.26	120	Near groundwater divide between two catchments, screened in the dacite of the Colinton Volcanics. Monitors baseline levels and water quality in area unlikely to be impacted by (i.e. background to) NH1a.
GGW06	43	Accessible location near top of hill between Jerrabomberra and Montgomery Creeks (control site)	789.87	120	Near groundwater divide between two catchments, screened in the dacite of the Colinton Volcanics and will monitor up-gradient (background) water quality and water levels in area unlikely to be impacted by the Googong Township development.
GGW07s	3	Within Beltana Park, close to Club Googong and an irrigated area	726.71	120	Located up-gradient of Beltana Pond in the soil and fill material. Monitors monitoring salt condition, water quality and surface/groundwater interactions near the pond.
GGW07d	19	Within Beltana Park, close to Club Googong and an irrigated area	726.67	120	Located up-gradient of Beltana Pond and down-gradient of the sports field. Screened in weathered shale monitors regional aquifer water levels and groundwater quality and surface/groundwater interactions near the pond.

B2.1.3 Groundwater monitoring bore design

The bores have been constructed to comply with the *Minimum Construction Requirements for Water Bores in Australia* (NUDLC 2012); the key design elements are shown in Figure 2.

All bores were drilled using rotary air and hammer techniques and were constructed using 50 mm class 18 screwed polyvinyl chloride (PVC) casing with machine slotted screens. An end cap was installed and the annulus backfilled with two to four millimetre nominal diameter sand to a level above the screen. A minimum one metre bentonite seal was installed above the gravel pack and the rest of the annulus backfilled or grouted to surface. A tamper proof steel monument was installed over the casing stickup.

HoboTM pressure transducers data logger (data logger) were installed in the monitoring bores. An additional data logger was installed in GGW01d in the air for atmospheric pressure compensation. All loggers were hung from a PVC cap via non-stretch rope and set to record at a one hourly interval.

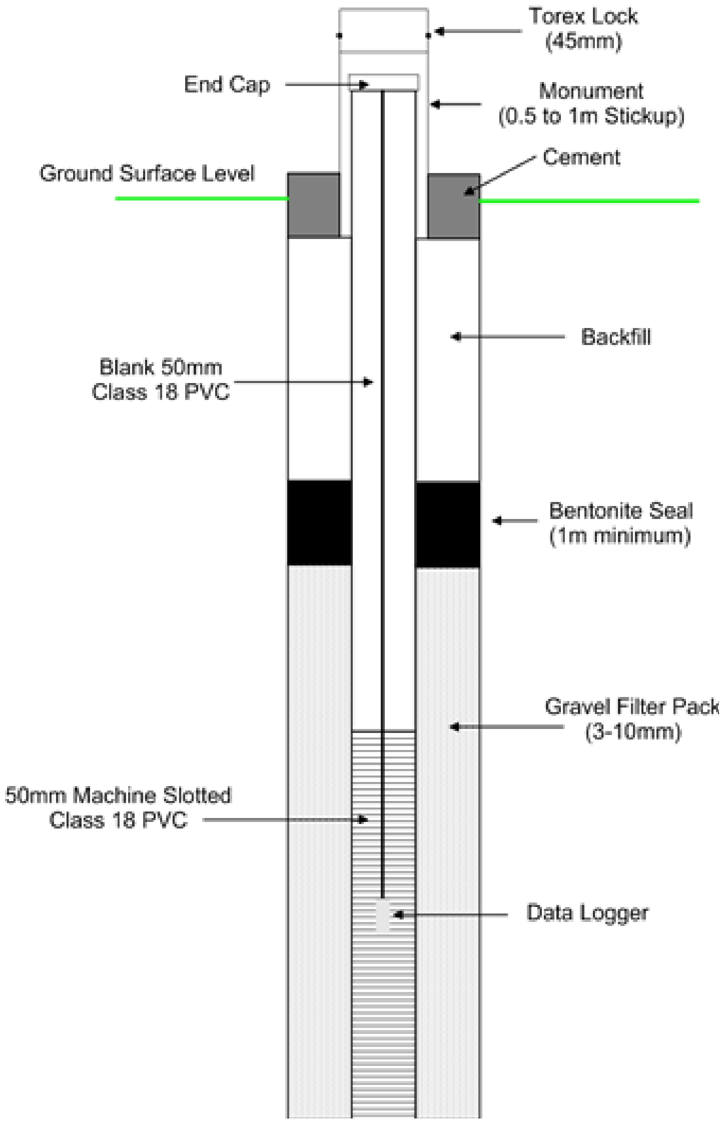

Figure 2 Generalised monitoring bore design elements (SMEC 2013)

B2.2 Monitoring methodology

Groundwater levels were monitored continuously through the use of data loggers and groundwater samples were collected on a quarterly basis for at least 12 months prior to operation of the water recycling plant (WRP), in order to gain a suitable database for characterising the baseline groundwater conditions at the site (SMEC 2015a).

B2.2.1 Groundwater levels

Groundwater levels were monitored manually using an electronic dip meter to the top of the PVC casing on a quarterly basis and hourly using a data logger. Data loggers were installed in the monitoring bores for the baseline year of monitoring (or longer if required). This allowed for collection and better understanding of:

- Intensive water level data at 3,6 or 12 hourly intervals.
- Assessment of rainfall recharge.
- Seasonal trends.
- Impact of pumping by existing users.
- Calibration targets for the groundwater model.

B2.2.2 Groundwater quality

Groundwater quality testing provides valuable information on the characteristics of groundwater beneath a site, but its representativeness of real conditions depends on the quality of the sampling methodology, and for this reason the sampling and analytical procedures needs to be undertaken rigorously.

Purging

The purpose of groundwater sampling is to retrieve a water sample that accurately represents the characteristics of water below the ground surface. To obtain a representative sample it is necessary to remove the stagnant water from the bore casing before a sample is taken, i.e. purging. Purging of each bore was undertaken prior to sample collection using an electrical submersible pump or appropriate sampling device (e.g. bailer). Where an electric submersible pump is used the pump was placed within the middle of the screened interval to draw formation water in quickly and reduce the purging time.

The volume to be purged aims to be either three casing volumes of water or until the monitored field parameters of pH and electrical conductivity (EC) stabilise to within 10% for three consecutive readings. If the bore ran dry during purging, sampling was performed, where practicable, the next day following recharge or the last volume of water extracted was taken as the sample.

Measurement of field parameters

Temperature, EC and pH were measured in the field as the value of the parameter can change after collection due to storage. The reason for selection of these in-field parameters is provided in Table 4. The in-field monitoring equipment sampling was calibrated in accordance with the manufacturer’s procedures and was calibrated at least once per year by a National Association of Testing Authorities (NATA) accredited servicing company. At the start of each monitoring round, calibration of the in-field meter was recorded.

Table 4 Groundwater in-field parameters

Analyte	Method	Practical quantitation limit (PQL)	Reason for selection
pH	Field multi-parameter probe	0.1 pH unit	Groundwater pH is a fundamental property that describes the acidity and alkalinity and largely controls the amount and chemical form of many organic and inorganic substances dissolved in groundwater. Provides overall indication of water quality to show broad trends and changes over time.
Temperature	Field multi-parameter probe	0.1 degree Celsius	The temperature of water directly affects many of its physical and chemical characteristics. Can also indicate the presence of aquifer inflows.
Electrical conductivity (EC)	Field multi-parameter probe	1µs	Convenient indirect measure of water salinity. EC is significantly affected by the temperature, so all results should be normalised to a standard temperature of 25°C.

Sample collection

Once the field parameters were stabilised as discussed in the previous section, a sample of groundwater was collected for chemical analysis. Groundwater was sampled from shallow boreholes using dedicated bailers, and from the deep boreholes using electrical submersible pumps.

For quality assurance purposes, during each sampling round a duplicate sample was collected from one borehole.

The sampling program was carried out in accordance with technical procedures outlined in this section. The methodology and quality of fieldwork was consistent with *National Environment Protection (Assessment of Site Contamination) Measure 1999* (NEPM) and the Environment Protection Authority (EPA) Victoria (2000) groundwater sampling guidelines endorsed by NSW EPA. Key elements of the sample collection and handling procedures included:

- Decon 90 was used to decontaminate field equipment. It is a phosphate-free biodegradable detergent that is environmentally safe and used industry-wide.
- a new pair of nitrile disposable gloves was used at each location to protect the sampler from exposure to potentially contaminated groundwater.
- samples were placed directly into chilled (ice) eskies for storage onsite and transport to the NATA-accredited laboratory.

Samples were placed in the appropriate sample bottles provided by the NATA-accredited laboratory and were filled according to laboratory instruction, i.e. zero head space where required. Some analytes are prone to precipitation and/or adsorbing onto sample bottle surfaces, and to ensure that the analysis results were as representative of actual conditions as possible preservatives were used. Samples collected for dissolved metals were field filtered, where practicable, through a 0.47 micron filter. The groundwater sample filtration and preservation techniques for each analyte are outlined in Table 3.

The sample labels included a sample identification number, sample location, sample date and the sampler's initials. Each identification number directly linked the sample to the borehole from which it was sampled.

Each quality control sample was labelled clearly, indicating whether it is a duplicate, and the sampler recorded the number of the bore from which the duplicate sample was obtained.

Table 5 Groundwater sample filtration and preservation techniques

Analyte	Container*	Preparation	Preservation
Anions (Cl, SO4, Br, Fl and HCO_3) Cations (Na, K, Ca, Mg, Fe, Mn) TDS and Nitrate calculation	1,000 mL green bottle	None	None
Trace Dissolved Metals (Fe, Si, B, Ba, Li, Sr, Al, Cu, Mn and Zn)	2 x 125 mL red and green stripe bottle	Filter through 0.45 µm HVLP membrane filter	None
Ammonia, Total Kjeldahl Nitrogen (TKN), Nitrate	125ml purple plastic bottle	None	0.5 mL ultra-pure sulphuric acid
TKN	40 mL glass vial, 500 ml plastic bottle	None	Acidify to < pH 2 with. Store in a cool place.

** Containers provided by NATA approved laboratory Australian Laboratory Services*

All activities conducted at each sampling event were documented on appropriate field forms and copies were included with the reporting. The following information was recorded:

- Date.
- Weather conditions.
- Method of sampling.
- Time of commencement and completion of sampling at each borehole.
- Depth to the standing water level from top of borehole casing.
- Length of water column.
- Sample intake depth.
- Field water quality readings.
- Any other relevant comments or information related to each individual borehole.

Chain-of-custody (CoC) procedures were used, so that samples could be tracked from the time of collection to the arrival of samples at the laboratory. Each sample container being shipped to the laboratory included a CoC form. A copy of the CoC form is included with the reporting.

Sample analysis

The baseline samples were analysed for a relatively broad range of inorganic and organic determinants, as set out in Table 4.

Table 6 Baseline groundwater sample analysis

Analyte	Method reference	Practical quantitation limit (PQL)	Reason for selection
Sodium	US EPA – 6010	0.5 mg/L	Baseline characterisation of major cations and anions enables better understanding of regional geochemistry, water type and the interaction of shallow and deeper groundwater.
Potassium	US EPA – 6010	0.5 mg/L	
Magnesium	US EPA – 6010	0.5 mg/L	
Calcium	US EPA – 6010	0.5 mg/L	

Analyte	Method reference	Practical quantitation limit (PQL)	Reason for selection
Sulphate	US EPA – 6010	1.0 mg/L	
Chloride	US EPA – 6010	1.0 mg/L	
Bicarbonate	US EPA – 6010	1.0 mg/L	
Total Dissolved Solids (TDS)	APHA 2540 C	1.0 mg/L	TDS is used as a 'lumped surrogate' measure of salinity in the ongoing monitoring, and it is important to be able to compare the TDS results to individual salt distributions during baseline characterisation.
Nitrate	APHA 4500-NO_3	0.01 mg/L	Speciated nutrients provide a useful insight into the geochemical behaviour of the groundwater and any interactions with additions of nutrients from surface or geochemical processes.
Ammonia	APHA 4500-NH_4	0.01 mg/L	
Total Kjeldahl nitrogen	APHA 4500-N_{org} D	0.1 mg/L	
Phosphorous – reactive	APHA 4500-P H	0.01 mg/L	
Copper	ORC/ICP-MS APHA 3125B	0.0005 mg/L	This selection of metals provides a good understanding of the baseline abundance and proportion of trace and heavy metals in the subsurface. The geology of the aquifer host rock will contribute a certain level of to the background metal reading that should be understood in order to assess any potential contamination. Total iron and manganese are also useful should groundwater extraction and discharge be required.
Cadmium	ORC/ICP-MS APHA 3125B	0.00005 mg/L	
Chromium	ORC/ICP-MS APHA 3125B	0.0002 mg/L	
Lead	ORC/ICP-MS APHA 3125B	0.0001 mg/L	
Nickel	ORC/ICP-MS APHA 3125B	0.0005 mg/L	
Zinc	ORC/ICP-MS APHA 3125B	0.002 mg/L	
Total iron	ORC/ICP-MS APHA 3125B	0.002 mg/L	
Total Manganese	ORC/ICP-MS APHA 3125B	0.002 mg/L	

B2.2.3 Soil salinity measurements

Two of the wells (GGW01s and GGW02s) have been designed to intercept shallow groundwater perched above the interface with unweathered bedrock. As both are to be located at the down-gradient side of proposed open space irrigation areas, they will provide important information on the behaviour of salts and will enable early detection of any systemic change in groundwater conditions, particularly salinity, which may result from irrigation or other practices at the development.

EC data loggers were installed at all shallow wells in early 2015. These will provide important ongoing information on the behaviour of salts. They will also enable early detection of any systemic changes in groundwater conditions which may be a result of the irrigation program or other practices within the development.

B2.2.4 Geophysical investigation

A ground electromagnetic survey using EM-31 and EM-38 ground conductivity meters, was carried out at the IWC Project site by Agsol (2010). As outlined in Section 4.1.4 of the WMP, the results of the investigation indicated that the conductivity of the ground (and hence salinity) was generally low. Higher values were noted, however, along the alignment of the waterways in NH1A, potentially indicating shallow groundwater and mobile salt discharge in these areas.

An additional geophysical survey was undertaken by SMEC, in conjunction with GBG Australia Pty Ltd from 29 September to 2 October 2014. This site investigation applied two geophysical methods – resistivity imaging and frequency domain electromagnetic measurements (FEM).

Two areas were targeted for this additional baseline geophysical survey - representing a known irrigation site (Site 1 – Rockley Oval), and down-gradient of the WRP (Site 2 – WRP). They were selected for practical access and repeatability purposes. These two sites also have groundwater boreholes within close proximity, which provide calibration information to aid the assessment. These survey sites are shown in Figure 3.

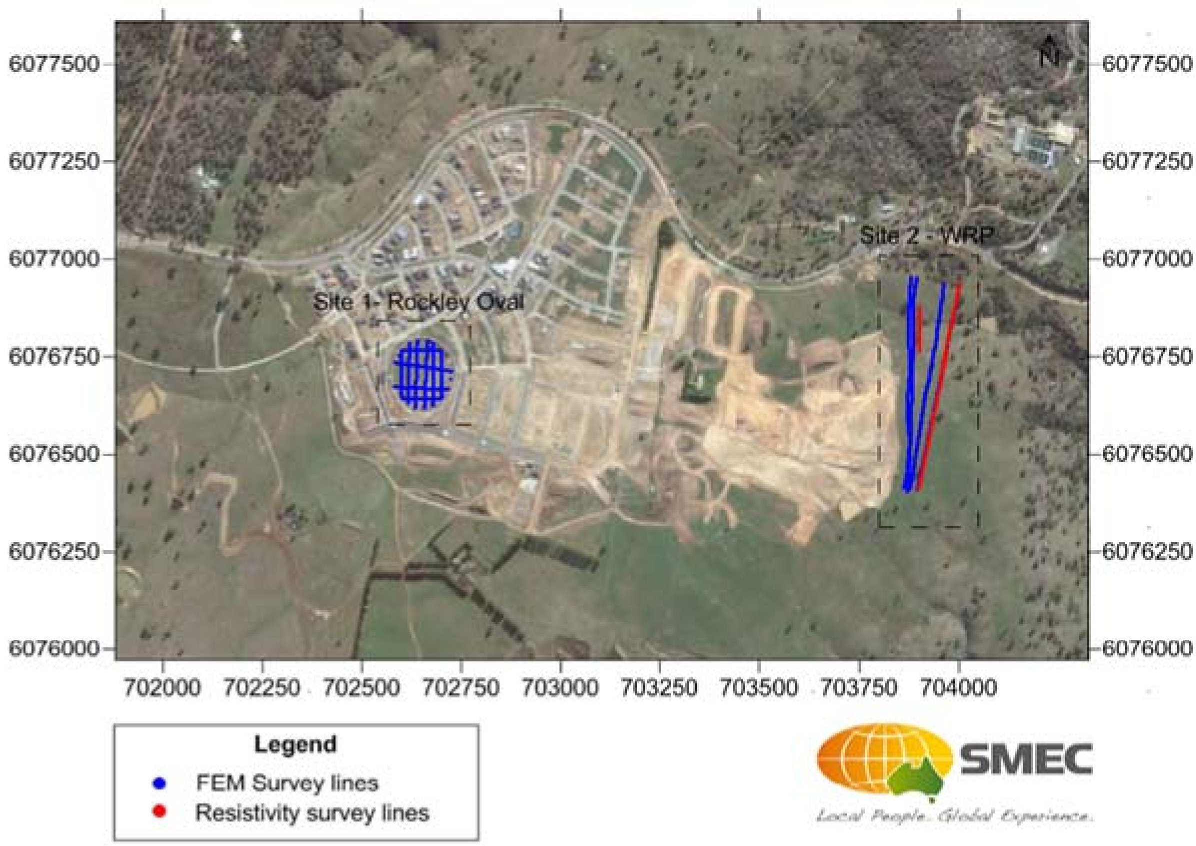

Figure 3 Overview of the two geophysical survey sites (SMEC 2015a)

Subsequent baseline geophysical surveys (using FEM) were undertaken in June 2015 and March 2016. Three areas were targeted for these additional baseline geophysical surveys:

- Area 1 - Rockley Oval, a known irrigation site (monitored in June 2015 and March 2016).
- Area 2 - Beltana Creek, down-gradient of Beltana Pond (monitored in June 2015 and March 2016).
- Area 6 - Duncan Fields, a known irrigation site (monitored in March 2016).

Again, the areas were selected for practical access and repeatability purposes. These survey sites are shown in Figure 4. The area down-gradient of the WRP, previously surveyed in October 2014 is no longer able to be surveyed due to interference from new overhead power lines and the presence of a new boundary fence.

Figure 4 Overview of the three geophysical survey sites (SMEC 2016)

Resistivity methodology

Resistivity profiles were acquired using a GF ARES 48 electrode resistivity system, using passive multicore cables. The GF ARES system uses a 48 electrode array and internal switching boards which performs the selection of the electrode configurations automatically, resulting in a combined resistivity image for each profile.

The electrode spacing was 2.5 metres for all profiles, with a half spread overlap roll on method applied, with a total resulting line length of 535 metres (combined lines 1 and 2) and a maximum exploration depth of approximately 22 metres at the centre of each profile.

The electrode position information was collected using a Trimble 5800 L1 L2 GPS system coupled to a Trimble Recon. The resistivity profiles were processed using Res2DInv software with both robust and combined standard least square inversion parameters, and used elevation data to produce topographically corrected sections. A summary of the inversions is provided in Table 5.

Table 7 Summary of resistivity inversions

	Profile 1	Profile 2	Profile 3
Inversion RMS error (%)	9.66	9.68	5.53
Data Levels	23	23	23
Model layers	12	12	12
Model Blocks	915	1,492	340
Data Points	1,339	2,154	529
Electrodes	96	144	48

Resistivity data was only acquired at Site 2 down gradient from the WRP, as the location of subsurface utilities at Site 1 would have adversely effected the results of the survey.

Frequency domain electromagnetics methodology (FEM)

2014 FEM monitoring

FEM data was collected using a GSSI Profiler EMP-400 conductivity meter coupled with a Trimble 5800 L1, L2 GPS system for location information. Data acquisition involved moving the device (combined transmitting and receiving coils) along profile lines across the area of concern with measurements taken at 0.2 second intervals.

The system outputs three frequency ranges at one time and records the returning in-phase and quadrature signal response, which are indicative of the soil conductivity profile. In order to gather a full suite of frequency ranges the lines had to be repeated three times by the operator with two differing frequencies and one static (5000Mhz) for correlation purposes, always beginning and ending at a predetermined calibration point to account for instrumental drift. Table 6 outlines the frequencies applied for each traverse.

Table 8 Summary of frequencies applied for FEM survey

	Traverse 1	Traverse 2	Traverse 3
Frequencies applied (Mhz)	14,000	8,000	5,000
	11,000	5,000	4,000
	5,000	3,000	1,000
Approximate Depth (m)	0.5 - 4	4 - 7	7 - 11

Surface anomalies that may affect the data are also recorded during acquisition to allow them to be disregarded during data interpretation.

From the results a plan view image is produced showing variations in the subsurface conductivity at various frequencies. This can be extrapolated into various corresponding skin depths for interpretation. Amplitudes of each frequency can also be plotted for correlation with other geophysical data along the same profiles.

2015 and 2016 FEM monitoring

FEM data was collected using a DualEM conductivity meter using both the two and four metre antenna/receiver separation (four metre only for the 2016 survey). Data acquisition involved moving the device along the profile lines with measurements taken at set intervals and surface anomalies which may affect the data also recorded during acquisition to allow them to be disregarded during data interpretation. The system has the ability to measure horizontal and vertical co-planar soundings allowing the zero to three metre and three to six metre depth ranges to be measured at the same time.

A set five metre station spacing was applied throughout the survey, with five metre profile/line spacing over Area 1 (Rockley Oval) and Area 6 (Duncan Fields), and ten metre spacing for Area 2 (Beltana Creek). GPS positioning data was acquired using a Garmin Oregon 550 GPS handheld system which used a minimum of eight satellites for accuracy over the survey. The survey and GPS data was processed in Surfer 11® with results plotted to produce plan view shaded conductivity maps within an approximate depth range.

B2.2.5 Groundwater modelling

A groundwater model of the Googong Township development (NH1A) has been developed by SMEC using a three-dimensional (3D) finite-difference groundwater model (MODFLOW) (SMEC 2015a).

The objective of ongoing flow modelling is to assess the long-term effects of the Googong Township development on the groundwater levels and groundwater quality, in particular relating to groundwater level variation and salt distribution due to irrigation. This is necessary so that changes to planning and management of later stages can be introduced if required.

Model development

Initial model development included:

- Data collation from the baseline monitoring, literature review and gap analysis.
- Characterisation of the groundwater environment, including identification of environmental values associated with groundwater resources.
- Development of the hydrogeological conceptual model (HCM).
- Development of a groundwater flow model to facilitate the assessment of the potential impacts of NH1A on groundwater resources.

The numerical groundwater model was constructed using MODFLOW-SURFACT and the graphical user interface Visual MODFLOW Version 2011.

Model design

The extent of the model domain was based on the appropriate site specific geological and hydrogeological boundaries. The model covers an area of approximately 106.5km^2 (Model Area), with the proposed Googong Township located in the centre. The model was designed for steady state and transient state simulation of groundwater flow.

The active model area (41.67 km^2) is bounded by:

- east and north Constant Head Boundary - following Googong Dam Reservoir and Queanbeyan River via tributaries and Googong Creek respectively.
- west and south no-flow boundary - coinciding with the surface / groundwater divide.

The boreholes in the study area encountered relatively uniform geological conditions underlying the site. The model is based on the HCM with two layers corresponding to the main geological units. The layers are:

- Layer 1: Top soil, highly to moderately weathered and residual clay over laying bed rock used to simulate the upper portion of the aquifer. It ranges in depth from two to 10 metres.
- Layer 2: Bed rock, slightly to highly fractured with an assigned thickness of 125 metres.

The model uses a 75 x 140 metre grid with 100 rows and 100 columns that was applied across the active model area.

Aquifer hydraulic parameters

Initially aquifer property estimates are based on previous works by CMJA (2010) and pumping test data analysis. Hydraulic property zoning was made based on the geology. Where no data is available literature values and professional judgement have been adopted. The calibrated aquifer parameters are summarised in Table 7.

Table 9 Calibrated aquifer properties for modelling purposes

Zone	Description	Horizontal hydraulic conductivity (m/day)	Vertical hydraulic conductivity (m/day)	Specific storage (m^{-1})	Specific yield
1	Colinton Volcanics (Tuff)	0.0025	0.00025	$1e^{-5}$	0.01
2	Colinton Volcanics (Limestone/Shale)	0.01	0.001	$6\ e^{-5}$	0.06
3	Googong Adamellite	0.18	0.018	$5\ e^{-5}$	0.05

Modelling approach

Modelling was undertaken in a staged approach to allow improved calibration and refinement of the adopted parameters.

The four modelled scenarios are:

- Scenario 1 – steady state.
- Scenario 2 – transient state.
- Scenario 3 – transient; assessment of irrigation impact on the water level under future climate.
- Scenario 4 – steady state; groundwater impact assessment due to residential development.

The first two scenarios were used to calibrate and verify the model as well as to examine the general response of the groundwater water level and flow system due to the climatic variables. Calibration was accomplished by applying a set of hydraulic parameters, boundary conditions and stresses that produced computer generated simulated pressure heads that matched actual field measurement within an acceptable range of error.

The steady and transient calibrated models were re-run to assess the impact of development (including the irrigation) on the post construction period.

A transient simulation, Scenarios 3 was carried out to estimate the effects of irrigation on the groundwater system for the next two years (post- September 2014), assuming the 2014-2016 rainfall rate to coincide with the 2010-2012 period. Scenario 3 was undertaken to simulate the effect of irrigation on groundwater levels at the monitoring wells based on recommended monthly irrigation depths for the nominated areas.

Scenario 4 is designed specifically to assess the potential impact of irrigation in the area on the water quality. The MODPATH package was employed to define flow paths from the irrigation areas using the particle tracking method. The determination of the flow path assisted in conceptualising and delineating salinity susceptibility in the Googong Township area due to irrigation practices (particles tracked forward towards the downstream location).

B2.3 Results

B2.3.1 Baseline monitoring (2013 – 2014)

Bore yields and aquifer hydraulic properties

Yields for boreholes drilled throughout the Googong surrounds vary – reportedly from less than 0.1 L/s in some of the bores drilled in the Late Silurian Colinton Volcanics, up to about 10 L/s for a few bores drilled in the Colinton Volcanics and into the margins of the Barracks Creek Adamellite. Most of the bores, however, have been drilled in the Colinton Volcanics where yields are more modest and typically range between 0.5 and 1.0 L/s.

Most of the higher-yielding bores were drilled in the ignimbrite and metasedimentary units of the Colinton Volcanics, although a few higher-yielding bores have also been drilled along the southern margin of the Barracks Creek Adamellite where enhanced fracturing and deeper weathering profiles are thought to exist. Boreholes that have encountered multiple water-bearing zones seem to have markedly higher yields, and in most instances yields appear to increase with depth. The highest-yielding water-bearing zones throughout the area were typically identified at depths of between 20 and 50 metres, beyond which the degree of fracturing is thought to decline markedly, particularly in the Silurian intrusions.

A monitoring bore network was installed for the IWC Project between 13 August and 5 September 2013 and consists of eleven monitoring bores, comprising four shallow and seven deep bores. Further details of the groundwater monitoring undertaken, including the locations of the bores, are provided in Sections B2.1 and B2.2.

The drilling details for the bores, including bore yield, screened interval and lithology are provided in Table 8.

Table 10 Summary of groundwater bores drilling details

Bore ID	Total depth drilled (m)	Final airlift yield (L/sec)	Screened interval (mbgl)	Screened lithology
GGW1S	10.5	NA	7.5 to 10.5	Limestone/shale
GGW1D	19	0.14	13 to 19	Shale/limestone
GGW2	8	NA	5 to 8	Adamellite/dacite
GGW3S	7	NA	4.5 to 7	Adamellite
GGW3D	25.6	0.03	18.5 to 25.6	Dacite
GGW4S	7	NA	4 to 7	Shale/Phyllite
GGW4D	55	0.05	44 to 55	Shale/Phyllite
GGW5	43	0.02	32 to 43	Dacite
GGW6	43	0.16	25 to 43	Dacite
GGW7S	3	NA	1 to 3	Fill – sandy clay
GGW7D	19	NS	7 to 19	Shale/Phyllite

Note: NA – Not assessed; NS – not enough for sample

Standing water levels, groundwater flow and gradients

Data from existing groundwater bores indicates that the regional standing water level ranging between 10 and 30 metres below ground level (mbgl) (at the time of drilling). Slightly deeper levels have been noted where the bores have been drilled on ridgelines or hill slopes. Perched aquifers are predicted to be present, especially after large rainfall events. This shallow groundwater will be perched above the top of the weathered bedrock and flow throughout the study area will be heavily influenced by the local topography, with local and regionally significant peaks and ridges delineating local groundwater divides in both the shallow (ephemeral) and deep (regionally connected) aquifers. The regional groundwater within the study area flows in a northerly direction, into the Queanbeyan River catchment, with most expected to discharge to the north north-east and lower reaches of the river.

As well as local groundwater divides between the Jerrambomberra, Googong and Montgomery Creek sub-catchments, CMJA (2010) predicted that there is likely to be a groundwater divide between these sub-catchments and the Googong Dam in the south-eastern part of the larger Googong Township development site.

Groundwater hydrographs for all the baseline monitoring bores with rainfall data and cumulative residual monthly rainfall mass (CRMRM) are shown in Figure 5.

The CRMRM compares the actual cumulative monthly rainfall with the long term average monthly values to establish a trend in terms of periods of above or below average rainfall. As the onsite weather station was operational from September 2013 there was insufficient data to undertake a CRMRM assessment with the years' worth of rainfall data. Therefore the rainfall data from the Bureau of Meteorology (BOM) Queanbeyan Bowling Club weather station was used between 2000 and 2014.

The CRMRM is a useful tool for determining drivers for water level changes in hydrographs and aids in the identification of impacts caused by factors other than climate. Where a water table aquifer is responding to climatic variations the hydrograph will tend to mirror the CRMRM.

Figure 5 indicates that average rainfall conditions are apparent between August 2013 and January 2014 and May 2014 to September 2014. Above average conditions are apparent between January 2014 and May 2014. Whilst rainfall at Queanbeyan might not be truly reflective of rainfall on the site the average trend of the climate condition is likely to be similar.

Based on Figure 5, the following observations can be made for each groundwater monitoring bore:

- GGW1S, screened in limestone/shale, was dry up until December 2013 following significant rainfall in November 2013. The data logger was installed in December 2013 and shows rapidly declining groundwater levels. In general this monitoring bore is dry however it does respond to significant rainfall events, such as either high rainfall or prolonged periods of rain.
- GGW1D, screened in shale/limestone, shows significant increases in groundwater level following rainfall events, as well as a decline in groundwater level during the May to September 2014 period of below average rainfall. Since installation the groundwater level has fluctuated over almost four metres in response to rainfall events. This monitoring bore is located near the deeply incised Googong Creek in an area where a minor limestone lens occurs. This lens may be fault related. The limestone is weakly metamorphosed but joints may provide conduits for direct rainfall recharge and thus rapid rises in groundwater level. Overflow from Beltana Pond to Googong Creek may also influence the groundwater level observed, particularly where no significant rainfall is apparent to correlate with rising groundwater levels.
- GGW2, screened predominantly in adamellite, shows an overall decline in groundwater level of around one metre since installation. Recovery from sampling events is reasonably slow suggesting low

permeability and there does not appear to be a significant response to rainfall events. The groundwater level showed a delayed increase of approximately 0.5 m following the period of rainfall between March and April 2014.

- GGW3S, screened in adamellite, and GGW3D, screened in dacite, show very similar groundwater levels suggesting they may be weakly interconnected. Both show a rise in groundwater level following the rainfall period in March 2014. GGW3S also shows a significant rise in groundwater level in July 2014 and this is attributed to flooding of the borehole following a heavy rainfall event. The ground level surrounding this monitoring nest has been raised approximately two metres since July 2014 and the monitoring bores have been extended accordingly. Overall GGW3S shows the groundwater level has declined approximately 0.5 m between September 2013 to March 2014 and 0.5 m from May 2014, excluding the flooding event.
- GGW3D, screened in dacite, shows a generally stable groundwater level from September 2013 to March 2014. In March 2014 the groundwater level rose approximately one metre before gradually declining 0.5 m. The groundwater level does not appear to show significant responses to rainfall with the exception of the March 2014 rainfall event.
- GGW4S, screened in the 'perched' shale aquifer, shows a relatively stable groundwater level over the monitoring period. No response is observed from the January 2014 pumping test. The groundwater level rose approximately 0.5 m following the March 2014 rainfall event. No other responses to rainfall were observed.
- GGW4D, screened in the regional shale aquifer, shows a relatively stable groundwater level over the monitoring period. The logger trace is very similar to GGW4S, suggesting the aquifers may be weakly connected.
- GGW5, screened in the regional dacite aquifer, shows overall relatively stable groundwater level. The groundwater level decreased 1.1 m following the pumping test in January 2014 and has since remained stable around this level. No significant response to rainfall events was observed.
- GGW6, screened in the regional dacite aquifer, shows a decrease in groundwater level in December 2013 following sampling and no apparent recovery with a slight overall decline to March 2014. The groundwater level in March 2014 rose around five metres in response to rainfall before slowly declining. A further rise is observed in May 2014 in response to rainfall followed by a gradual decline. No significant response is observed during the January 2014 pumping test however the lack of recovery following sampling in December 2013 may possibly be influenced by the pumping test.
- GGW7S, screened in fill material above Beltana Pond, shows a relatively stable groundwater level over the monitoring period. Small rises in groundwater level are observed following rainfall events in March 2014, June 2014 and September 2014.
- GGW7D, screened in the regional shale aquifer, shows a relatively stable groundwater level over the monitoring period with the exception of a small rise in response to rainfall in March 2014. No significant response was observed in relation to the January 2014 pumping test.

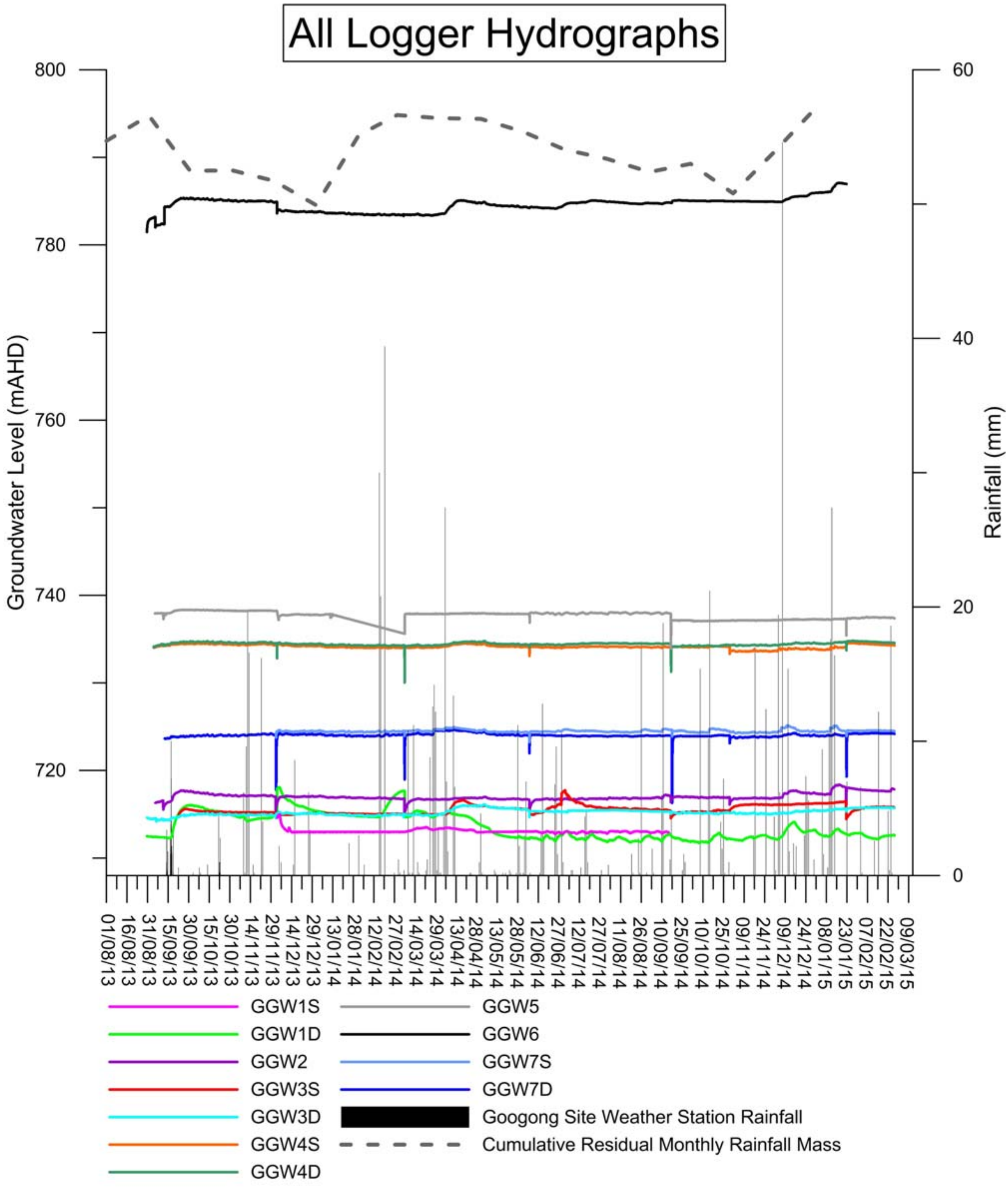

Figure 5 Groundwater hydrographs for all monitoring bores (SMEC 2015a)

Contoured groundwater levels for the deep aquifers recorded in September 2014 and interpreted flow direction are shown on Figure 6. The groundwater flow direction is north-east towards the Queanbeyan River.

The shallow or 'perched' groundwater aquifers will flow in the general direction of surface water drainage, e.g. GGW1S towards Googong Creek and GGW2 and GGW3S towards Googong Dam.

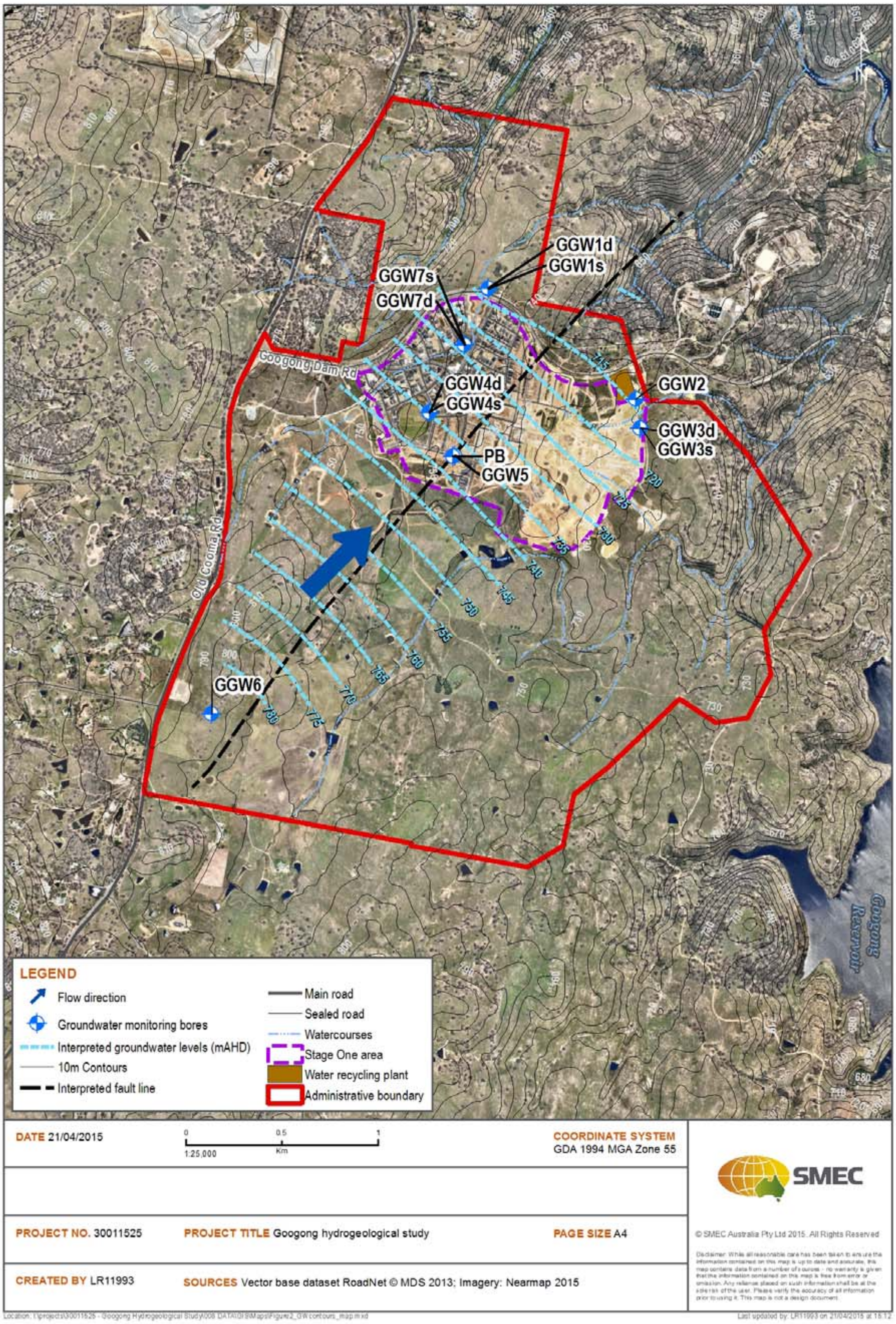

Figure 6 Interpreted deep groundwater level (mAHD) and flow direction (SMEC 2015a)

Groundwater quality

Data from existing groundwater bores indicates that the regional groundwater is considered to have relatively low TDS. The TDS (salt) in most of the bores is below 1,200 mg/L, which is considered to be within the acceptable limits for human consumption.

The range of in-field water quality parameters recorded during baseline monitoring are summarised in Table 9.

Table 11 Groundwater field water quality parameter ranges

Bore ID	pH	Electrical conductivity (µS/cm)	Temperature (°C)
GGW1S	7.11 – 7.22	680 – 723	15.6 – 16.8
GGW1D	6.70 – 8.02	696 – 1,148	15.4 – 16.6
GGW2	5.81 – 7.70	728 – 1,198	13.5 – 17.1
GGW3S	7.29 – 8.10	425 – 730	14.6 – 17.5
GGW3D	6.70 – 7.39	1,335 – 1,995	16.0 – 16.6
GGW4S	6.57 – 7.37	1,838 – 2,013	14.7 – 17.2
GGW4D	6.72 – 7.99	800 – 1,589	15.5 – 16.9
GGW5	6.48 – 7.81	1,354 – 1,589	14.6 – 17.3
GGW6	6.43 – 7.81	1,123 – 1,323	15.2 – 16.5
GGW7S	6.65 – 8.05	625 – 1,803	11.9 – 20.3
GGW7D	6.69 – 8.05	1,134 – 1,468	15.5 – 18.2

The following observations were made regarding field pH:

- Groundwater pH generally ranged between 6.5 and 8.
- pH generally decreased between the September 2013 and June 2014 monitoring rounds and then rose between June 2014 and September 2014.

The following observations were made regarding field EC:

- Groundwater EC generally ranged between 696 and 1,468 µS/cm for the regional 'deep' aquifer and 425 and 2,013 µS/cm for the shallow 'perched' aquifers.
- GGW2 and GGW3S showed decreasing EC over the monitoring period.
- GGW7D showed increasing EC over the monitoring period.
- Low EC (425 µS/cm) in GGW7S in December 2013 most likely reflects recharge from potable fresh water that was used to irrigate recently planted vegetation near the bore, however water level fluctuations are subdued in this bore making correlation with watering or rainfall difficult.
- EC is consistent with the geology of the screened aquifers and anticipated background water quality.

Construction activity was occurring within the Googong Township throughout the baseline monitoring period, related to both the IWC Project and residential development works. Table 12 outlines the differences in water level and EC at the bores prior to construction and during construction. In general water quality (EC) is affected by site activities, while water level remains relatively unaffected.

Table 12 Water level and electrical conductivity background and construction-impacted ranges

Bore ID	Background ranges			Construction impacted ranges			Period of construction impact ranges
	Water Level (mAHD)	Field EC (uS/cm)	Logger EC (uS/cm)	Water Level (mAHD)	Field EC (uS/cm)	Logger EC (uS/cm)	
GGW1S				713 to 715	680 to 723	No Logger	From Sept 2013 to Feb 2015
GGW1D				716 to 712	696 to 1148	845 to 1,025	From Sept 2013 to Feb 2015
GGW2	716.8 to 717.5	728 to 1198	1,175 to 1,350	717.4 to 718	693 to 718	700 to 750	From Dec 2014 to Feb 2015
GGW3S	715 to 716.5	584 to 730	500 to 510	717 to 715.5	425 to 512	470 to 510	From June 2014 to Feb 2015
GGW3D	714.8 to 716	1,335 to 1,995	No Logger				
GGW4S				733.5 to 734.4	215 to 1208	1,000 to 2,100	From Sept 2013 to Feb 2015
GGW4D	734.2 to 734.7	800 to 1025	No Logger				
GGW5	737 to 738.4	1,354 to 1,724	No Logger				
GGW6	783.5 to 786	1,123 to 1,340	No Logger				
GGW7S				724.3 to 725	625 to 1843	1,300 to 1,825	From Sept 2013 to Feb 2015
GGW7D				723.7 to 724.5	1134 to 1564	1,450 to 1,550	From Sept 2013 to Feb 2015

Laboratory analysis of groundwater samples was undertaken, and the groundwater chemistry data was entered into a water chemistry analysis program. Piper diagrams[3] were produced for all samples from September 2013 to September 2014 for each piezometer nest.

[3] *A piper diagram is a way of visualising the chemistry of a rock, soil, or water sample. It's comprised of three pieces: a ternary diagram in the lower left representing the cations, a ternary diagram in the lower right representing the anions, and a diamond plot in the middle representing a combination of the two.*

A tight cluster of points for each round indicates generally consistent groundwater chemistry. The following exceptions were observed:

- GGW1S showed slight increase in chloride (Cl) and sulphate (SO_4) in December 2013.
- GGW2 showed variable bicarbonate (HCO_3) to carbonate (CO_3) range for the first three rounds with consistent results observed for June and September 2014. This suggests disturbance during drilling or impacts from the activities up gradient at the WRP site.
- GGW3S showed increasing SO_4.
- The September 2014 result for GGW4D was considered an outlier and may represent sample, preservation or laboratory issues.
- The September 2013 result for GGW5 was an outlier and likely reflects contamination by drilling fluids from drilling of the production bore.
- The September 2014 result for GGW7S was an outlier and may reflect recent rainfall.

There were two distinctly different clusters of results for GGW3S and GGW3D, reflecting the different aquifers. Similarly, two distinct clusters of results were observed for GGW4S and GGW4D. These results represent the difference between the weathered shale 'perched' aquifer and the regional shale aquifer.

Table 11 outlines the calculated water type for each round. The same water type is calculated for GGW1S, GGW1D, GGW3S and GGW3D each round of the monitoring period. The same water type is also calculated for GGW5 and GGW6 for each round excluding the September 2013 round; and GWW2 for each round excluding the December 2013 round.

Water type for GGW4S, GGW4D, GGW7S and GGW7D does not remain constant across the five monitoring rounds, although they are all bicarbonate, sulphate type with variable metals (calcium (Ca), magnesium (Mg), sodium (Na) and iron (Fe)), except GGW4S that was Mg-Cl type in March 2014. It is considered these changes reflect natural variations that may be exacerbated by the act of sampling (i.e. drawing down the water level more than would naturally occur followed by recovery).

Table 13 Groundwater chemical water type and screened lithology

Bore ID	Sept 2013	Dec 2013	March 2014	June 2014	Sept 2014	Screened lithology
GGW1S	Dry	Ca-HCO_3	Ca-HCO_3	Dry	Dry	Limestone/shale
GGW1D	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Shale/limestone
GGW2	Na-HCO_3	Na-SO_4	Na-HCO_3	Na-HCO_3	Na-HCO_3	Adamellite/dacite
GGW3S	Na-HCO_3	Na-HCO_3	Na-HCO_3	Na-HCO_3	Na-HCO_3	Adamellite
GGW3D	Mg-HCO_3	Mg-HCO_3	Mg-HCO_3	Mg-HCO_3	Mg-HCO_3	Dacite
GGW4S	Mg-HCO_3	Mg-HCO_3	Mg-Cl	Mg-HCO_3	Na-HCO_3	Shale/Phyllite
GGW4D	Na-HCO_3	Ca-HCO_3	Ca-HCO_3	Mg-HCO_3	Ca-HCO_3	Shale/Phyllite
GGW5	Na-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Ca-HCO_3	Dacite
GGW6	Ca-SO_4	Mg-SO_4	Mg-SO_4	Mg-SO_4	Mg-SO_4	Dacite
GGW7S	Mg-SO_4	Fe-HCO_3	Mg-SO_4	Mg-HCO_3	Mg-HCO_3	Fill – sandy clay
GGW7D	Fe-HCO_3	Mg-HCO_3	Mg-SO_4	Mg-HCO_3	Mg-HCO_3	Shale/Phyllite

The parameters of interest for recycled water discharge to the environment in CoA D5 of the Project Approval are biological oxygen demand (BOD), total suspended solids (TSS), total nitrogen, total phosphorous, TDS, faecal coliforms, pH, free chlorine, ammonia and oil and grease. Of these, the baseline groundwater monitoring program assessed TDS, total kjeldahl nitrogen (TKN), nitrate + nitrite as N, reactive phosphorous, pH and ammonia.

Figure 7 shows a time series plot of TDS for the monitoring bores. Over the monitoring period the TDS has remained relatively consistent, with the exception of GGW3S and GGW3D in the September 2014 round. The increase in TDS at these bores is related to the flooding of the bores in July 2014 after heavy rain caused water to build up in the earth bund that surrounded them during the construction of the new sports field and associated earthworks.

In terms of the nutrient parameters, the following observations were made:

- Total nitrogen in the monitoring bores ranged from <0.01 to 8.2 mg/L. The highest recorded nitrogen was in GGW3D in March 2014.
- Nitrate and Nitrite ranged from < 0.01 to 8.2 mg/L and <0.01 to 8 mg/L respectively, with the highest recorded nitrate in GGW3D in March 2013 and nitrite in GGW3S in June 2014.
- Total reactive phosphorous ranged from <0.01 to 0.03mg/L with the highest recorded in GGW2 in September 2014.
- Ammonia ranged from <0.01 to 1.1mg/L with the highest recorded in GGW5 in September 2013.

Nutrients detected in the groundwater at GGW2, GGW3S and GGW3D are likely to reflect the sheep grazing history of the site prior to construction.

All the background levels are below the environmental discharge criteria for recycled water in the WMP. Changes in these monitored parameters after irrigation with recycled water commences may indicate a potential impact from irrigation.

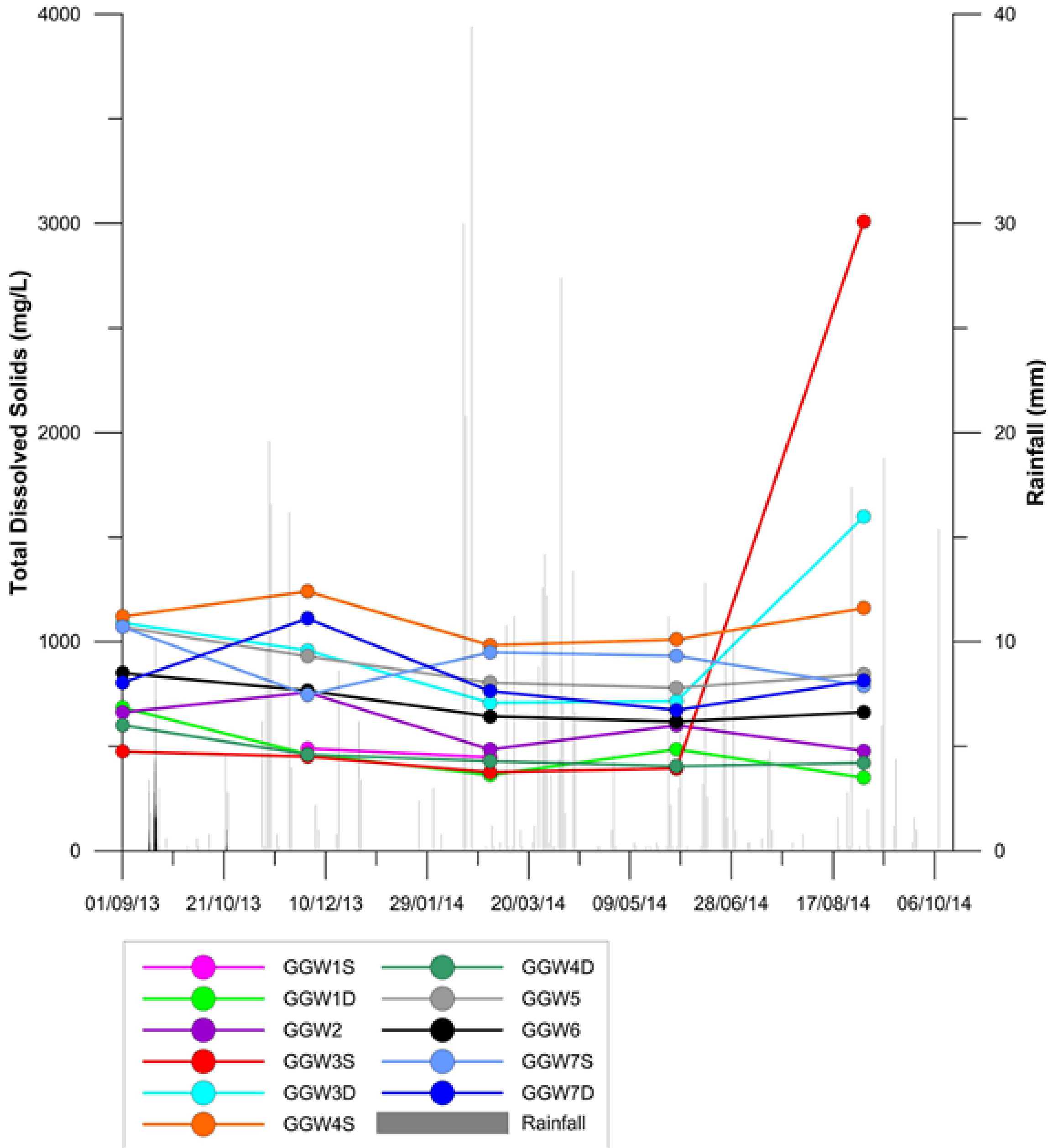

Figure 7 Time series plot of Total Dissolved Solids in groundwater (SMEC 2015a)

Groundwater recharge and discharge

Recharge

Rainfall recharge of fractured-rock aquifers occurs through areas of open fracturing, either at the surface or through superficial unconsolidated material. In the latter case, there may be a delay between a rainfall event and the entry of water into the aquifer, due to storage in the unconsolidated material of the recharge zone.

Recharge of the aquifers would occur mainly via infiltration of rainfall, infiltration of slope runoff, and outflow from the Queanbeyan River and Jerrabomberra Creek (and other watercourses) during periods of high flow and flooding events. Overall, recharge in the area is expected to be limited by the generally low rainfall, particularly during winter months.

Discharge

Discharge from the aquifer is thought to occur primarily through natural flow from springs, both perennial and ephemeral, and from baseflow into perennial watercourses. Other discharges from the aquifer include bore pumping for domestic and stock purposes, whilst some localised irrigation is also likely. No springs or 'soaks' were observed at the site, but it is noted that the monitoring was carried out in a relatively dry period. No significant rain had fallen in the area for some time.

Groundwater utilisation and vulnerability

Groundwater in the region is predominantly used for a combination of domestic and stock purposes. It is expected to be of sufficient quality for general water supply purposes, and it may be suitable for potable use without requiring any form of treatment.

Mapping of the vulnerability of groundwater sources to contamination is provided by the NSW Office of Environment and Heritage (OEH). Five classes of vulnerability ranking are chosen to describe the probability of contamination to groundwater resources. They include: 'low', 'moderate', 'moderately high', 'high', and 'very high'. More than 90 per cent of the Googong Township area has been ranked as having moderate vulnerability.

Groundwater dependent ecosystems

The Environmental Assessment (Manidis Roberts 2010) and SMEC (2015a) did not identify the presence of groundwater-dependent ecosystems within the vicinity of the Googong Township area. Accordingly, it was determined that impacts on groundwater-dependent ecosystems resulting from operation of the IWC Project are unlikely.

B2.3.2 Additional baseline monitoring (January-February 2015)

A scheduled quarterly baseline monitoring round was undertaken in January 2015 by SMEC, which identified exceedances of the revised trigger levels outlined in the Googong Annual Groundwater Report (SMEC, 2015a). The following exceedances were identified during the January 2015 monitoring round:

- Field EC measurement in GGW5.
- EC data loggers in GGW2, GGW4S and GGW7D show extended periods of EC above trigger levels.
- Ammonia in GGW3S and GGW4S.
- Nitrite in GGW2, GGW3S, GGW5 and GGW6.
- Chromium in GGW4S.
- Copper in GGW7S.

SMEC undertook a non-scheduled sampling round to assess if these exceedances may be in response to natural baseline variations or other factors, such as onsite activities. The outcomes of this additional monitoring round were detailed in a memo entitled *Results of Additional February 2015 Monitoring Round and Recommendations* (SMEC 2015b). The following exceedances were identified during the non-scheduled February 2015 monitoring round:

- Field quality measurements – EC at GGW5 (1,699 µS/cm).
- EC data loggers – no exceedances between January 2015 and February 2015.
- Nutrient measurements – total nitrogen at GGW4S (2.7 mg/L); nitrate at GGW2 (6.81 mg/L).
- Heavy metals – no exceedances.

SMEC reviewed the January and February 2015 monitoring results and concluded the following:

- In GGW5 field EC measurements are likely representative of baseline conditions for both monitoring rounds.
- In GGW3S ammonia and nitrite (January 2015) and nitrate (February 2015) likely represent disturbed conditions from the earthwork construction activity in the area.
- GGW4S had been drilled into an area of fill that contained an old farm dam. This bore has had a sulphurous smell to the water each sampling round and rust has been observed inside the borehole monument. The fluctuation in nutrient levels may be a result of decomposing organic matter from the base of the dam. The interaction of this with rainfall and changes in water level appear to result in the production of acids and the degassing hydrogen sulphide. The hydrogen sulphide is suspected of causing accelerated rust on the inside of the bore monument. Acid production may cause the leaching of various things and may explain the chromium exceedance. This bore is considered suitable for monitoring water levels in the shallow bedrock in this location but may not be suitable for monitoring quality due to the disturbance from the buried dam.
- In GGW6 nitrite (January 2015) likely reflects baseline conditions.
- GGW7S was installed in the fill material near the sediment retention pond next to Beltana Pond. This bore is not considered representative of “background” groundwater conditions. It is designed to monitor the interaction and quality of the water entering the pond and shallow soil profile. The bore provides background conditions ‘post construction’ of the pond and should be used to assess trends in the water quality and provide a pre-irrigation baseline.

B2.3.3 Geophysical investigation

Two areas were initially targeted for baseline geophysical survey - representing a known irrigation site (Site 1 – Rockley Oval), and down-gradient of the WRP (Site 2 – WRP). The site investigation applied two geophysical methods – resistivity imaging and FEM, as outlined in SMEC (2015a).

Subsequent baseline geophysical surveys (using FEM only) targeted an additional two areas - representing down-gradient of Beltana Pond (Area 2 – Beltana Creek) and a known irrigation site (Area 6 – Duncan Fields) (SMEC 2015c and SMEC 2016). Surveys were again also completed at Rockley Oval (referred to as Area 1). The area down-gradient of the WRP, was not surveyed due to interference from new overhead power lines and the presence of a new boundary fence.

Site 1 – Rockley Oval (also referred to as Area 1)

2014 resistivity and FEM monitoring

Site 1 displays an amplified shallow (0.5 m) conductivity response when compared to the non-terraformed Site 2 down gradient from the WRP (see Figure 8). Rockley Oval appears to have approximately one metre of sand fill applied above the made surface and a generally higher conductivity response when compared to Site 2. This is possibly due to residual fertiliser contained within the newly laid turf. Site observations support this conclusion as those areas of higher conductivity also displayed more fertile grass growth. However differing moisture contents within the soils could also create this variation.

The removal of rock and disturbance of the topsoil (soil horizon) would also likely release conductive minerals that could become mobilised and concentrated by surface runoff in areas of lower topography such as the oval. There appears to be a correlation between the soil samples results taken from the oval and the FEM data acquired as displayed in Figure 8. Due to the conductivity of the large stormwater drain running diagonally across the oval, very little variation is observable from the lower frequencies that correspond to depths deeper than approximately two meters. This is likely due to signal attenuation, and additionally the masking effect of the higher conductivity of the pipe when compared to the small variations of the background signal.

Overall the disturbed local soils around the oval had a higher conductivity (254-317 µS/cm) than the sandy soil used as fill under the oval (116-162 µS/cm). Therefore this will be valuable to resurvey and assess for potential shallow conductivity changes (increased salinity) after the commencement of irrigation.

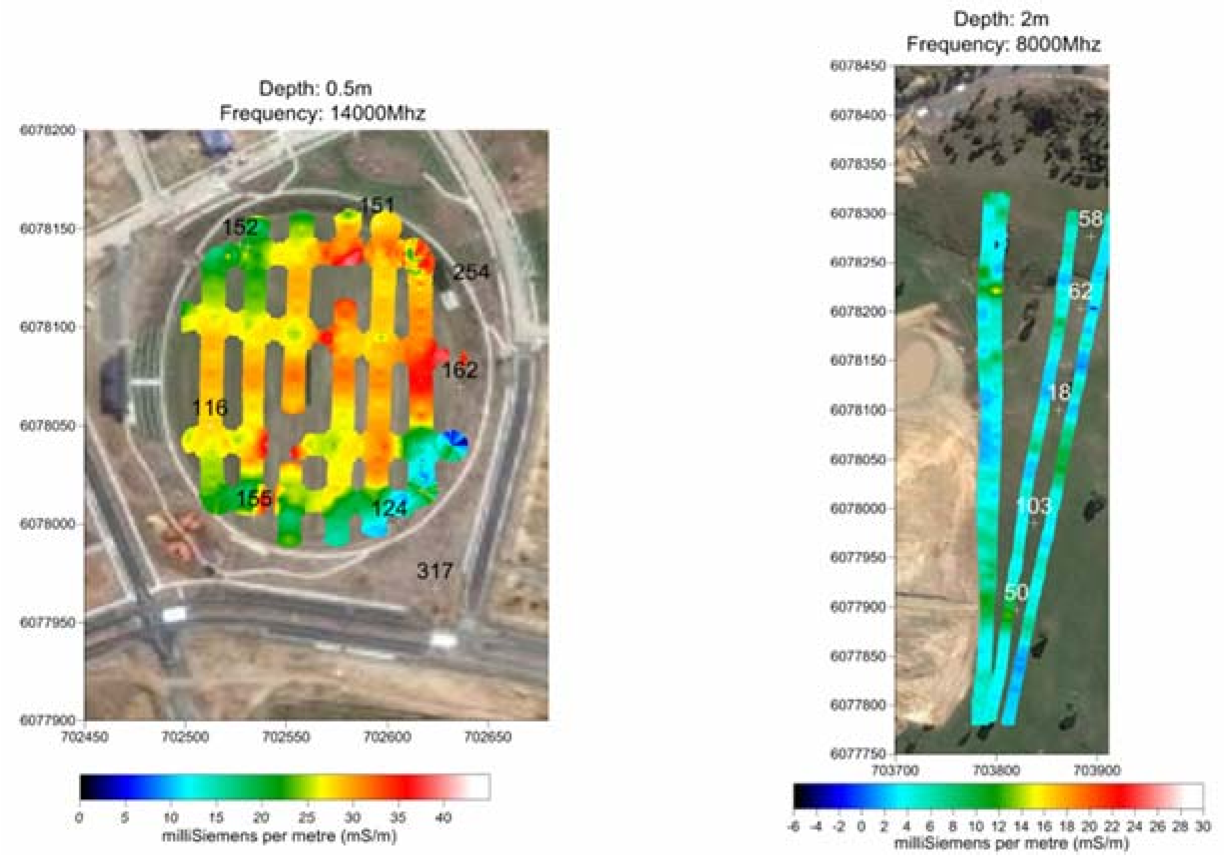

Figure 8 FEM data in relation to plotted soil sample results (µS/cm) at Site 1 (left) and Site 2 (right) (SMEC 2015a)

2015 and 2016 FEM monitoring

The results of the 2014, 2015 and 2016 FEM surveys of Rockley Oval are showed in Figure 9. It can be observed that the main features (e.g. the stormwater drain) appear consistent and in general there is no significant evidence of change between June 2015 and March 2016. There is a small degree of broadening of the shallow zones of higher (yellow) conductivity.

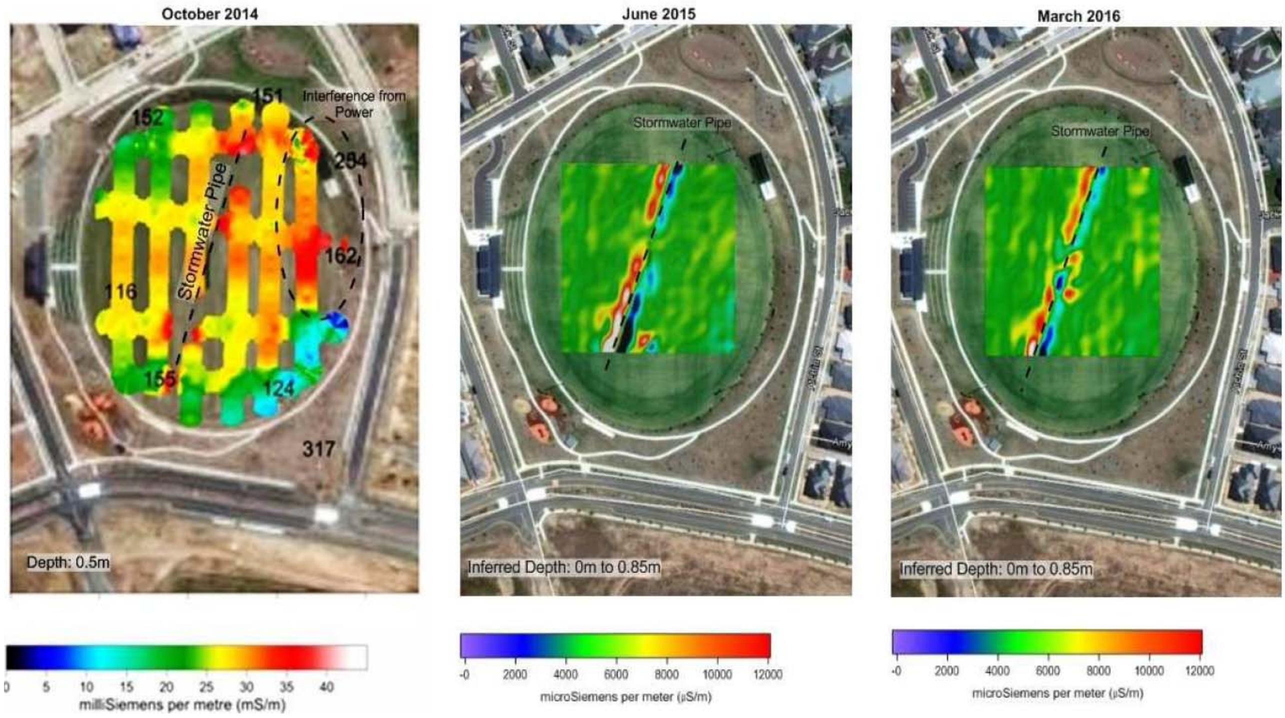

Figure 9 Comparison of FEM conductivity contour plots from October 2014, June 2015 and March 2016 for Rockley Oval (SMEC 2016)

The high conductivity stormwater drain can still be seen running diagonally across the oval in a southwest/northeast orientation. The conductivity of the shallow soil profile over Rockley Oval is generally in the range of around 4,000 to 8,000µS/m, with a preferential north/south pattern evident within the data. This visual pattern is likely attributed to the orientation in which the turf was originally laid and the imported soil entrained within the turf.

The areas of moderately higher conductivity (e.g. yellow colours) appear to coincide with areas of more fertile turf growth. It is likely that this effect can be attributed to one or a combination of a few of the following factors:

- Some zones may retain more water due to different entrained material directly underneath the turf (i.e. higher clay content);
- Water logging/pooling due to less efficient drainage or surface depressions;
- Non-consistent irrigation coverage over the oval;
- Distribution of fertiliser is not consistent over the oval;
- Differing grass species planted; or
- Replacement of failed turf after initial installation.

From these factors, generally the largest effect on the FEM responses is that of soil moisture content. Seasonal fluctuations, and the duration between rainfall events are likely contributing factors which cause subsurface conductivity fluctuations.

Application of fertiliser and the distribution of irrigation outlets, which apply water to the oval, are also likely to have an impact however the turf structure and subsoil materials ability to retain moisture under the turf is likely to be the overall dominating factor.

Site 2 – Down gradient of the WRP

Interpretation of the resistivity data reveals a number of features that are believed to relate to faults or fracture zone structures, which are generally more conductive than the surrounding material.

From site observations and the data, there is an anticipated change in strike direction of the strata over the surveyed area. This strike variation is visible from a north-south orientation (parallel to the survey direction) in the south; to a west-north-westerly direction (to the north towards the WRP). This structure is possibly indicative of the overall regional geology, amplified by localised faulting. Within this area a corresponding fault/shear zone structure is interpreted from the data, accompanied by a conjugate set of faults (or fractures) towards the north of the site (Figure 10). These structures could provide conduit pathways for the subsurface movement of groundwater or a resistive impermeable barrier. At the drainage line there is a further change in strike of the fault / fracture to an east west alignment.

There are two zones on Figure 10 (blue circles) of higher conductivity/lower resistivity that could be suggested as highly saturated zones. These two zones juxtapose faults (inferred from the data and geological site observations) and are potentially hosted within zones of highly fractured rock, presenting pathways for shallow groundwater flow.

The soils within the region down slope of the WRP are generally of low conductivity with the exception of the near surface region bounded by the two drainage lines (which form a V shaped wedge) immediately to the south of the WRP site (Figure 8). There is evidence of runoff from the excavation in this area that is accompanied by an increase in conductivity (albeit a small magnitude) from the near surface FEM data.

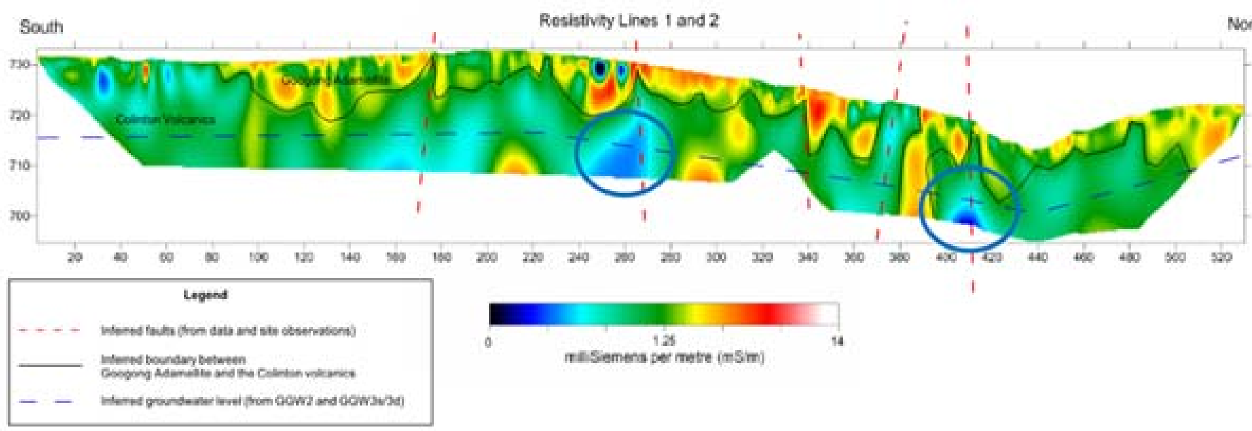

Figure 10 Pseudosection of Resistivity data with annotated interpretations (SMEC 2015a)

Area 2 – Beltana Creek

The survey area below Beltana pond (down gradient of GGW1S and GGW1D), runs along a section of Googong Creek, and is unaffected by construction activities. It is considered to represent an *in situ*/natural soil profile. The survey is located across the creek line and drainage area (refer to Figure 11).

Overall a conductivity range of 10,000 to 22,0000µS/m was recorded, which is characteristic of metamorphic rocks or shale. From the drilling logs of adjacent boreholes GGW1S and GGW1D and surface outcrop observed during the survey, it is known that limestone is present with a block alignment roughly parallel to that of the creek.

In general limestone has a lower conductivity than shale. The resistive/low conductivity bedrock boundary to the west, observed as limestone, appears to have a steeply dipping contact with the alluvial / weathered zone which possibly extends to the underlying shale rock at depth.

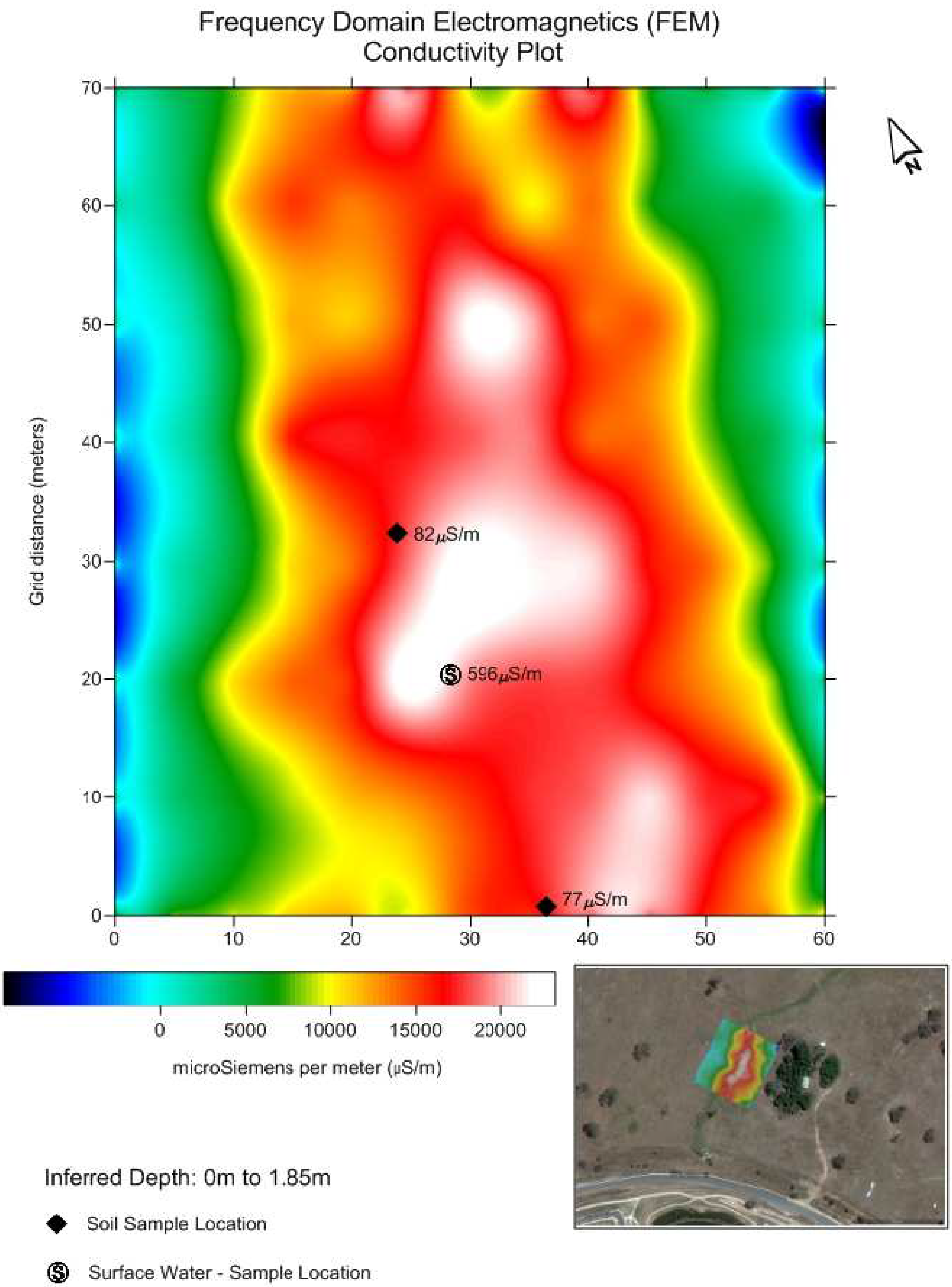

Figure 11 Comparison of FEM conductivity contour plots from June 2015 and March 2016 for Beltana Creek (SMEC 2016)

Area 6 – Duncan Fields

The baseline FEM survey of Duncan Fields prior to recycled water irrigation is shown on Figure 12. In general, site conductivities range from 1,000 to 8,500µS/m. This narrower range is likely due to the type of fill materials used (sand), providing a well-draining subsoil. The fill materials are represented by conductivities less than approximately 4,000µs/m (green and yellow colours). A similar correlation can be suggested as with Rockley oval, with zones of moderately higher conductivity (yellow) appearing to coincide with areas of more fertile turf growth. This is likely due to a number of factors including the application of fertiliser, the distribution of irrigation outlets, and the manner and material associated with the turf laying process.

There are 4 dipole effects (a circular high and low conductivity response) in each corner of the survey area which are caused by the metallic goal posts. These were not considered significant enough to be filtered from the data.

The feature most of interest in this survey is the high (red and white) conductivity zone running through the centre of the site. The cause of this high is unclear but may be related to either the geology/structure underlying the oval, a geological anomaly such as dyke or contact, the type of fill material placed in this area, or the way the turf was placed.

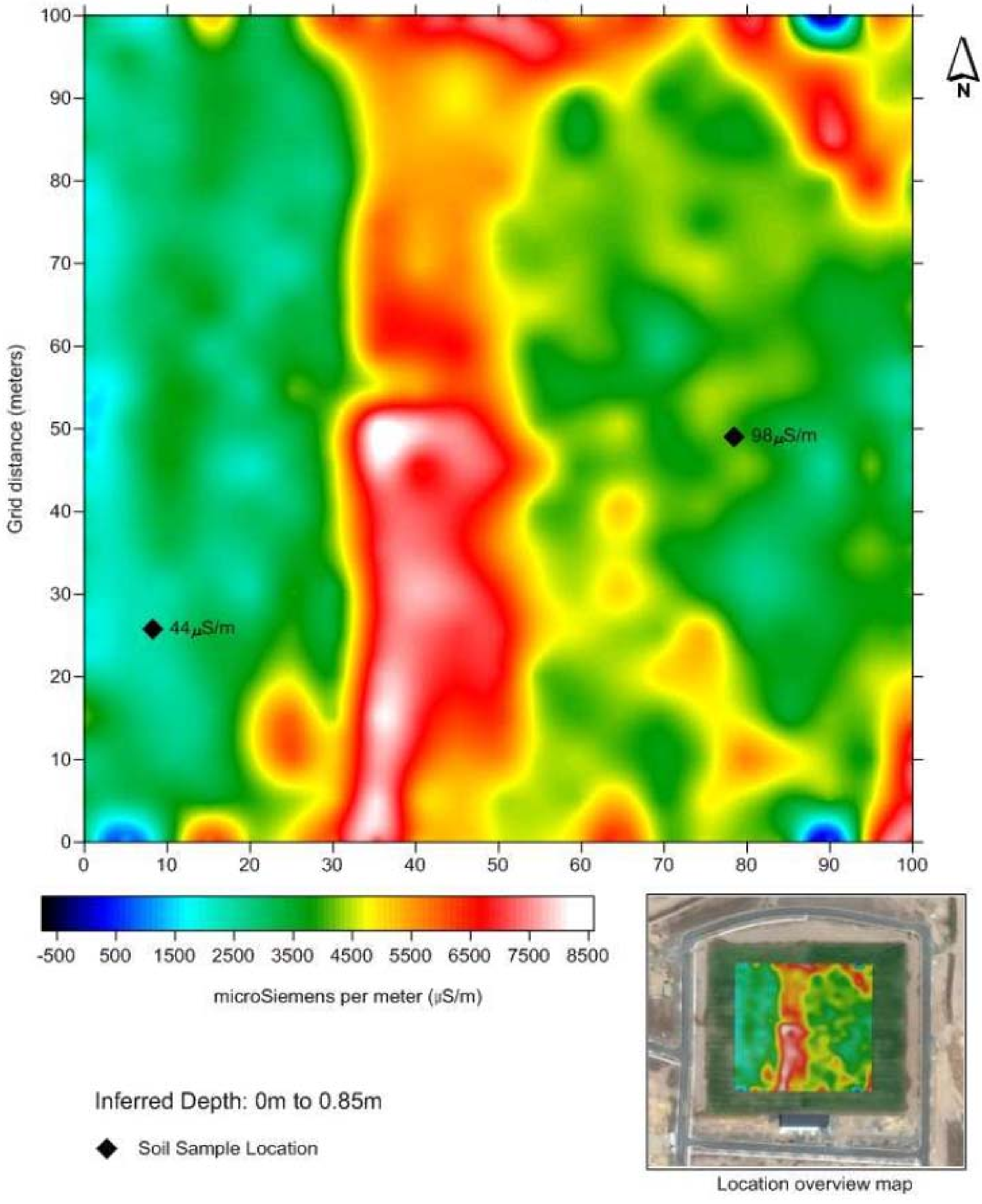

Figure 12 FEM conductivity contour plot of Area 6 – Duncan Fields (SMEC 2016)

B2.3.4 Groundwater modelling

The groundwater scenarios modelled indicated the following:

- an increase in recharge due to irrigation is less significant in relation to the water level rise, as outflow from the Queanbeyan River (and other watercourses) during periods of high flow, irrigation (induced recharge) and flooding events are capable of removing excess recharge. In other words, the net gain of recharge water available from irrigation will result in minimal water level increases across most of the site, which will in turn result in increased baseflows to waterways down-gradient of the site, and an increased amount of water stored in the aquifer. This will inevitably result in thicker saturated water-bearing zones throughout the irrigation area. Moreover, recharge in the area is likely to be limited by the generally low rainfall in the area, and is expected to decline post-development due to the expected decline in recharge across the site (due to paved and built areas).
- There is a low level of potential overall groundwater quality impact, as indicated by a slight increase in storage over the simulation period, given the response from increased river leakage/base flow, evapotranspiration and constant head out via creeks and tributaries.
- The flow path from the irrigation area in NH1A follows a path line via observation wells – GGW01s and GGW02s, which are designed to intercept shallow groundwater perched above the interface with unweathered bedrock. Although some changes to the groundwater system are expected at the site following the path line, no major impacts on the water stored in the Googong Dam reservoir are anticipated. The expected groundwater flow directions beneath much of the proposed development area will see any impacted groundwater migrate to the north and northeast of the site, ultimately draining to the lower reaches of the Queanbeyan River below Googong Dam. Furthermore, impacted groundwater in the eastern portion of the site is expected to drain to Montgomerys Creek (or one of its few tributaries), which forms a type of natural groundwater capture drain through the centre of this portion of the site. Again, groundwater in this area discharges to the lower reaches of the Queanbeyan River.

In order to better understand whether salinisation is likely to become a significant issue at the site, salt levels (EC) in the waterways will be regularly monitored during and after the development of NH1A as part of the Surface Water (and Aquatic Ecology) Monitoring Program.

B3 Groundwater Dependent Ecosystems

At this stage, no groundwater dependent ecosystems have been identified in the area, which is consistent with the significant depth to groundwater. No further action is required at this time.

B4 Groundwater impact assessment criteria

B4.1 Background

CoA D8 requires in part that the WMP must include 'groundwater impact assessment criteria, including trigger levels for investigating any potentially adverse groundwater impacts'. A trigger level is a criterion which if exceeded would result in further action, in this case further investigation and assessment to determine whether ongoing monitoring indicates a deviation from the baseline characteristics, potentially as a result of irrigation or other operational practices.

B4.2 Interim trigger levels for baseline monitoring

Interim trigger levels based on existing guidelines were originally set for the IWC Project as no project-specific background information on groundwater levels and quality was available for the site.

An interim trigger for groundwater levels within shallow monitoring wells (GGW01s, GGW03s, GGW04s and GGW07s) was set equivalent to one metre beneath the base of the root zone within the irrigation areas.

For the assessment of potential human health issues relating to the consumption of bore water in the area, it was considered that the appropriate interim criteria are found within the *Health Guidelines in Australian Drinking Water Guidelines* (NHMRC & NRMMC 2011). These levels relate specifically to water that is to be used for human consumption, and although they do not represent mandatory standards for the quality of water for human consumption, they do offer a framework for identifying acceptable water quality. It should be noted that the use of groundwater for drinking water is not proposed for Googong Township.

For the assessment of potential environmental impacts arising from the interaction of groundwater with freshwater aquatic ecosystems, it was considered appropriate in the absence of baseline data that the interim criteria and trigger values set for the protection of 95 per cent of species in fresh water and listed in Table 3.4.1 of *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC 2000) be used as trigger levels. For phosphorus, the most applicable trigger level available is that for protection of slightly disturbed aquatic ecosystems in upland streams, designated in Table 3.3.2 of ANZECC (2000) as 20 µg/L.

On this basis, the published criteria for both human health and environmental concerns are presented in Table 12 as interim trigger levels for groundwater quality. Trigger values included are the values applying to slightly–moderately disturbed systems, and have been derived for use in assessing surface waters. In the absence of specific levels for groundwater, the surface water trigger values were used.

However, it was noted in previous studies (CJMA 2010) that the proposed development is to occur in an area of relatively low-quality and degraded farmland. Further, the review of available groundwater quality results from regional bores indicates that current groundwater concentrations for a number of the parameters provided in Table 12 would already exceed current health and environmental thresholds for further investigation. Accordingly, these interim trigger levels have been re-assessed following baseline groundwater monitoring, as outlined in the next section.

Table 14 Interim trigger levels for groundwater quality (prior to baseline monitoring)

Analyte	Drinking water health guidelines (mg/L)[1]	Trigger values for the protection of freshwater aquatic ecosystems (mg/L) [2]
pH (field + laboratory)	6.5 – 8.5	6.5 – 7.5
Total Dissolved Solids	500	-
Sodium[3]		-
Chloride[3]		-
Sulphate	250	-
Fluoride	1.5	-
Ammonia as nitrogen (N)	0.4	0.74
Nitrate as N	11	0.175
Nitrite as N	0.75	-
Phosphorus (total)	-	0.02
Arsenic (As III)	0.007	0.024
Cadmium	0.002	0.0002
Chromium (Cr III)	-	0.0033[4]
Copper	2	0.0014
Iron[3]		0.3[4]
Lead	0.01	0.0034
Mercury	0.001	0.00006/0.0006
Nickel	0.02	0.0011
Zinc	ISD[5]	0.008
Naphthalene	-	0.016

Note:

1. *NHMRC/NRMMC (2004)*
2. *ANZECC (2000)*
3. *No health-based guideline necessary*
4. *Low reliability figures which should only be used as indicative interim working levels*
5. *ISD Insufficient data to set a guideline value based on health considerations*

B4.3 Revised trigger levels for ongoing monitoring

B4.3.1 Background

As stated above, ANZECC (2000) criteria are designed to be applicable to surface water quality. They are only relevant to groundwater if it is either to be extracted and directly discharged to a surface water body, or a natural groundwater discharge point is located on or directly adjacent to the site. For the Googong Township, the regional groundwater flow direction is towards the Queanbeyan River as this is its natural discharge point. Based on the groundwater contour levels, discharge to Googong Creek from the regional aquifer is unlikely. The shallow / perched aquifers may contribute to the creek down gradient of the site.

Without background monitoring points down gradient it is not practical to assess changes to water quality where offsite activities cannot be controlled. Therefore the ANZECC (2000) criteria should only be considered as a guideline where background monitoring data is unavailable or limited.

There are no plans to extract groundwater for human drinking consumption within the Googong Township. The private bore survey (SMEC December 2013 Quarterly Groundwater Monitoring Report) and preliminary groundwater assessment (CJMA 2010) also identified that most private bores in the area are used for stock and/or domestic purposes. The quality reported does not appear suitable for human drinking water and the two private bores that were assessed by SMEC were only used for garden watering and firefighting. Therefore it is not considered necessary to assess the groundwater quality against the drinking water guidelines at this stage.

B4.3.2 Development of trigger levels

Triggers for implementing additional investigations or responses were recommended by SMEC (2015a) following one year of baseline monitoring. The revised triggers allowed for the natural range of variability in the perched and regional aquifers. They represent selected criteria that are considered most indicative of a potential impact to the groundwater system from irrigation with recycled water.

For the groundwater level trigger, no specific value has been set for the monitoring bores. Where a consistent trend of increase or decrease is observed over three consecutive monitoring rounds or there is a sudden significant change that does not appear to be related to climate e.g. decrease or increase in rainfall, then this is considered the trigger for further assessment of potential impacts.

Each piezometer shows a different range of values and thus specific values have been set for parameters at each piezometer. The trigger values for physical parameters and nutrients were derived as a 25 per cent increase or decrease, where appropriate, based on the range of values measured over the one-year period.

The dissolved heavy metals were analysed at ultra-trace levels that means detection down to very low levels of 0.05 to 0.01 µg/L. Most results were below the detection limit and those that were not were generally below the standard limit of detection for the analyte tested. Trigger levels were set to either:

- 10 per cent above the standard limit of detection; or
- 25 per cent of the background range.

As outlined in Section B2, additional baseline monitoring was undertaken in January and February 2015, which identified exceedances of the revised trigger levels outlined in the Googong Annual Groundwater Report (SMEC 2015a). SMEC (2015b) provided the following recommendations in terms of updating of the revised trigger levels, based on the recorded exceedances and site observations:

- The groundwater sample results of GGW5 and GGW6 were considered as representative of variations in background groundwater conditions. Therefore the preliminary trigger levels for these bores were revised to include the January and February 2015 sample round results.
- GGW4S and GGW7S were not considered as representative of natural ‘background’ groundwater conditions. GGW4S is considered suitable for water level monitoring, however due to the interference from the buried dam, a replacement or an additional shallow monitoring bore outside the disturbed area should be considered for monitoring water quality in the next network expansion.
- GGW7S was considered suitable to monitor the interactions and quality of water in the fill zone around Beltana Pond. It does not represent natural groundwater conditions but is important for salinity assessment. Trigger levels for this bore are therefore based on trends occurring prior to irrigation.

- Construction activities around GGW2 and GGW3S appear to have affected the shallow groundwater in this area. It is likely the effects will be temporary. Should exceedances continue after earthworks have finished further assessment might be required.

B4.3.3 Revised trigger levels

The revised groundwater trigger levels for physical parameters, nutrients and heavy metals are outlined in Table 13, 0 and Table 15, respectively.

Where a trigger level is exceeded the result will be assessed against climate conditions, other users (e.g. private bore pumping), construction related activities and irrigation loads, as outlined in the Surface Water and Groundwater Response Plan (Appendix D of the WMP).

These values will be reviewed and re-assessed annually, in line with review of this Program, as discussed in Section B5.

In addition, the EC loggers installed in the shallow wells will provide information on natural variations outside the sampling events. The data from these loggers will be used to inform ongoing trend-based assessment. For example, if a trend is for increasing EC with time regardless of seasonal variations (and if still under the trigger value) was observed then this would trigger further investigation, including additional sampling.

Table 15 Trigger levels for physical parameters

Bore ID	pH	Electrical conductivity (µS/cm)
GGW1S	<7 or >7.5	>740
GGW1D	<6 or >8.5	>1,260
GGW2	<5 or >8	>1,120
GGW3S	<7 or >8.5	>810
GGW3D	<6.5 or >7.5	>2,160
GGW4S	<6.3 or >7.5	>2,060
GGW4D	<6.3 or >7.5	>1,080
GGW5	<6 or >8	>1,750
GGW6	<5.8 or >8.8	>1,370
GGW7S	<6.3 or >8.4	>2,100
GGW7D	<6.3 or >8.4	>1,550

Table 16 Trigger levels for nutrients

Bore ID	Total nitrogen (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Reactive phosphorous (mg/L)	Ammonia (mg/L)
GGW1S	>4	>0.02	>3.7	>0.03	>0.03
GGW1D	>7	>4	>3.3	>0.03	>0.06
GGW2	>4	>3.1	>0.8	>0.03	>0.08
GGW3S	>12	>2.4	>9.8	>0.03	>0.1
GGW3D	>15	>4.6	>9.8	>0.03	>0.07
GGW4S	>0.5	>0.2	>0.2	>0.03	>1.5
GGW4D	>3	>1.7	>1	>0.03	>0.6
GGW5	>3	>4.6	>2.5	>0.03	>1.3
GGW6	>0.7	>0.72	>0.45	>0.03	>0.02
GGW7S	>2.5	>1.2	>1.2	>0.03	>0.15
GGW7D	>1.2	>0.61	>0.67	>0.03	>0.045

Table 17 Trigger levels for heavy metals

Bore ID	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Lead (µg/L)	Nickel (µg/L)	Zinc (µg/L)
GGW1S	>0.1	>0.85	>1.75	>0.2	>1.5	>30
GGW1D	>0.1	>0.32	>4.6	>1.8	>2.4	>52
GGW2	>0.4	>4.5	>5.2	>4.3	>1.8	>135
GGW3S	>0.46	>1.35	>5.7	>0.6	>1.1	>45
GGW3D	>2	>0.9	>16.5	>8.2	>3.4	>140
GGW4S	>0.2	>0.55	>1.6	>2.8	>13.5	>40
GGW4D	>0.1	>0.3	>6.5	>0.5	>1.2	>35
GGW5	>0.1	>0.45	>4	>0.7	>14	>200
GGW6	>2.2	>0.3	>28	>1.1	>5.5	>130
GGW7S	>0.25	>0.45	>1.55	>0.45	>6.7	>45
GGW7D	>0.4	>0.3	>5.8	>0.07	>4.3	>42

B5 Ongoing monitoring and reporting

B5.1 Ongoing groundwater monitoring

During the first year of operation of the WRP, the analytes listed in Table 4 will continue to be monitored, but on a bi-annual (twice a year) basis to enable an informed consideration of any impacts.

SMEC (2015a and 2015b) recommends that ultra-trace heavy metals analysis be replaced with standard trace heavy metals analysis. The current baseline data does not show heavy metal contamination to be of concern and removing the requirement of ultra-trace heavy metals will reduce long-term monitoring costs.

Should evidence of any impacts be indicated by the monitoring assessments in the way of exceedance of a trigger level provided in Section B4, further rounds of sampling will be undertaken which may to subjected to a more comprehensive analysis suite. An investigation into climate conditions, other users (e.g. private bore pumping), construction related activities and irrigation loads will also be undertaken, as outlined in the Surface Water and Groundwater Response Plan (Appendix D of the WMP).

SMEC (2015a) highlights the importance of the continuation of groundwater monitoring in the shallow monitoring bores, particularly the data recorded by the groundwater level and EC loggers in key shallow bores. This will provide important ongoing information on the behaviour of salts. It will also enable early detection of any systemic changes in groundwater conditions through trend-based assessment that may be a result of the irrigation program or other practices within the development.

At the end of the first year of WRP operation, a review of the monitoring network should be undertaken in accordance with future development planning for the township, as well as re-assessment of the analyte suite and trigger values. This would be undertaken as part of a review of this Program, in consultation with the relevant stakeholders.

Future changes to the ongoing monitoring program that may be considered include the rationalisation of the groundwater monitoring network to six sites following the first two years of operation.

B5.2 Ongoing geophysical investigations

Repeat surveying of the baseline geophysical investigation areas will occur after three and six months of irrigation with recycled water from the WRP. If no impacts or changes are assessed to have occurred, then the frequency of investigation will be undertaken as required. This will allow for the redistribution of salts beneath the site to be monitored and adaptive irrigation practices to be undertaken if evidence of significant salt increases is found, particularly in lower areas around waterways.

Areas proposed for recycled water irrigation but not currently geophysically surveyed, as they are yet to be completed, will be surveyed prior to the start of their scheduled irrigation. The investigative schedule during operation, as outlined previously, will also be followed for these additional sites.

The soil sampling undertaken as part of the geophysical investigation will continue in conjunction with this surveying program to sufficiently calibrate the FEM data, and monitor any potential changes in shallow soil salinity.

B5.3 Groundwater model updates

While qualitative descriptions of the likely impacts of the development have been assessed, it is not possible to provide quantitative descriptions or assessments of these impacts for the Googong Township as it requires consideration of the other neighbourhoods. Therefore, the model needs to be updated in line with this, including:

- Surface water monitoring results – specifically river gauging data and the location of these gauging stations.
- Onsite weather data.
- Integrated water cycle plan / irrigation plan – specifically planned irrigation areas and estimated daily or annual volumes of water to these areas and the planned discharge areas of excess water for the other neighbourhoods.
- Updated recommended application irrigation depths.
- Discharge rate or seepage face/height observed at the quarry site located north-west of the site that would help as a calibration target.
- Results of any additional geotechnical investigations that have occurred on the site.

The model should be run to expand to the whole site if planning has progressed far enough and extend to a maximum of 10 years of operation assuming no changes in irrigation areas. Climate change scenarios will be run for the 10 year simulation. The model will also assess the potential impact of a brine spill and constant leak from the WRP.

The groundwater model will be updated and re-run following the first two years of operational monitoring to assess the predicted versus actual effects. The existing model will be recalibrated with additional data (including regular geophysical survey results) and any changes to the development plans and long term scenarios re-run accordingly.

B5.4 Reporting

To aid the adaptive management processes prescribed for the IWC Project, the need to collate information generated through regular monitoring is required to improve future management.

Section 6.5 of the WMP states that reporting (which is to include the results and analysis of the groundwater monitoring), will be prepared annually. The reporting will be used to further refine measures to mitigate adverse environmental impacts that could occur as a result of the operation of the IWC Project.

B5.5 Program reviews and adaptive management

The GWMP will be an evolving document in response to monitoring objectives, monitoring results and periodic feedback in the form of regular reporting to inform ongoing management. It will incorporate adaptive management outcomes with regard to regular reporting inputs and in consultation with the operator, relevant stakeholders, regulatory bodies and relevant experts.

A timeline of management objectives and actions to the end of year one of operation is detailed in Table 16. Ongoing management objectives at the end of year one will be evaluated at that time to consolidate monitoring results and consultative feedback to date.

Table 18 Proposed timeline of adaptive management processes in response to groundwater monitoring.

Management objective	Outcome	Action	Timeline
Baseline Monitoring (COMPLETED)	Inform the operational monitoring requirement of the IWC Project.	Dependent on results of baseline monitoring an annual report would recommend measures to mitigate adverse environmental impacts through the establishment of impact criteria and refined trigger values.	Quarterly monitoring to be completed for at least 12 months (prior to proposed WRP operation). Report at the end of 12 months of monitoring.
Groundwater flow modelling (COMPLETED)	Inform the operational monitoring requirement of the IWC Project.	Dependent on results of baseline monitoring groundwater modelling would be carried out to assess the long-term effects of the Googong Township development and climate change on groundwater recharge, groundwater levels and groundwater quality.	At the completion of baseline monitoring.
Operational Monitoring	Collate operational six-monthly monitoring on an annual (reporting) basis to document any changes in specific environmental indicators.	Identify potential impacts of the operation of the IWC Project. Recommend mitigation measures to reduce impacts if identified.	Samples taken bi-annually. Report annually.
Ongoing update and review (annual review).	Update and refine monitoring program on the basis of data collected to date in consultation with the regulator.	Consider impacts and control measures instituted to date and refine the scope of the monitoring program accordingly to incorporate additional monitoring sites or environmental indicators (e.g. toxicants) as part of ongoing monitoring.	Annually.

B6 References

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