



resource and environmental management

Buckland Park EIS

GROUNDWATER INVESTIGATIONS

- Final Report
- 17 December 2008

SINCLAIR KNIGHT MERZ

SKM



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Executive Summary

The Buckland Park Site is 32 km north of Adelaide. Potential groundwater issues associated with the proposal have been identified in the Environmental Impact Statement guidelines by the Development Assessment Commission. Resource and Environmental Management (REM), now merged with Sinclair Knight Merz Pty. Ltd., was engaged to investigate various groundwater issues. This report primarily addresses the issues associated with shallow groundwater at the site. The content of this report is based on desktop work, field investigations and groundwater flow modelling using all available information.

This report specifically addresses the following objectives:

- Description of the existing hydrogeological conditions affecting the site and its locality by undertaking a desk top study and detailed field survey.
- Description of the high unconfined water table(s) that exists in this area, including the predicted movement over the short and long term and the risk this represents to infrastructure, including housing stock.
- Identification of measures that could be applied to manage these risks (“...the high unconfined groundwater water table(s) that exists in this area”) in the short and long term.
- Description of measures to protect the Gawler River and coastal environments during operations.
- Description of the short and long term effects of constructing waterways for detention purposes on land and/or groundwater quality and movement, especially salinity.
- Description of any special engineering requirements for infrastructure due to the expected high water table in this area including the cost of developing and maintaining infrastructure for saline and acid sulphate soils, seasonal variations in height and groundwater rise due to sea level rise.
- Quantitative assessment of on-site groundwater hazards.

The Buckland Park site covers approximately 1,308 hectares adjacent to the Gawler River 32 km north of Adelaide. The land is characterised as low lying and low coastal relief plain. Two natural watercourses drain the area: the Gawler River and Thompson Creek. The climate is a mild Mediterranean climate with hot dry summers and cool, wet winters. Average annual evaporation exceeds average annual rainfall by almost four times. During wet periods the Gawler River may flood and overflow is channelled along Thompson Creek. Cheethams salt lakes are located between the Buckland Park site and the coast.

The Buckland Park site is underlain by a series of shallow aquifers that are hydraulically connected. These are composed of intercalated sands, silts and clays. Groundwater levels are typically shallow particularly where clay layers cause local perching. Salinity levels vary widely across the site but increase dramatically to hypersaline levels in the vicinity of the salt lakes.

A series of 11 new monitoring wells were drilled to obtain site specific information within the Buckland Park site. All wells were sampled for groundwater levels, salinity, hydraulic conductivity and hydro-geochemistry. Results from these surveys were used to improve the conceptualisation of groundwater



processes within and around the Buckland Park site which was used in the establishment of a numerical model.

The lithological information indicates near surface geology is highly variable both across the study area and with depth and contains a high proportion of clay and clayey sediments at depths of less than 4m below ground level. These clays act as an impediment to downward movement of water and may result in the development of perched watertables. Depth to groundwater is generally shallow and varies from around 8 m in the northeast of the site to less than 2 m in the south west. Problems associated with waterlogging and salinity are most likely to occur in areas where the depth to groundwater is less than 2 m below ground level. Groundwater flow is predominantly from the northeast to the southwest.

A steady-state numerical model was developed to model the interaction of groundwater within the Buckland Park site and adjoining regions. This model conceptualises the aquifer system as three layers underlain by an impervious aquitard at 20m. The lithological data was interpreted as forming layers from 0-5 m, 5-10 m and 10-20 m with varying proportions of sand, silt and clay and differing hydrogeological properties. Groundwater levels were set from interpreted groundwater contours along the eastern and western boundaries, recharge was determined as a proportion of rainfall and discharge via evapotranspiration was set from assumed values. This model was calibrated against the recently measured groundwater levels from the field survey and a model calibration error (mean relative error) of 6.8% was achieved.

Modifications were then made to the model in order to conduct predictive scenario modelling. These included a reduction of 50% to the recharge and 30% to the maximum evapotranspiration rate beneath the development footprint (due to the large area of paving), the inclusion of new proposed drainage and the option of examining a 0.3 m rise in sea-level as a result of climate change.

These results indicate:

- There will be minimal falls in groundwater levels as a result of the Buckland Park proposal; and
- The impacts on groundwater from a climate change-induced rise in sea level will be restricted to the coastal zone and largely confined to the area beneath the salt lakes.

Additional spreadsheet modelling was conducted to determine the impact of stormwater retention on groundwater levels. Results from the stormwater retention modelling indicate unless the channels and ponds are lined, a groundwater mound may form in an area surrounding the pond, thus increasing the risk from rising groundwater and shallow watertables in adjacent areas. The mound will effectively reduce the salinity of shallow groundwater within the mound perimeter as a result of the leakage of low salinity stormwater.

The impacts of engineering works were considered and a range of groundwater mitigation options examined. Of these most require pumping to a detention basin for disposal via evaporation. It is considered unlikely an active groundwater disposal scheme would be developed. Temporary storage of high salinity groundwater may be required for deep trenching works, and under these circumstances a carefully located lined retention pond is recommended.



The shallow and often saline watertable presents a potential threat in the Buckland Park site if irrigation practices in residential areas are poor, resulting in excess infiltration. The watertable is shallow and salinity impacts are evident in areas of the site, particularly in the lower southwest sectors. In the context of residential development, the relative risk of urban salinity is provided by the combination of groundwater depth in the regional watertable aquifer and the occurrence of subsurface clay in the upper 4 m of the soil profile. The approach adopted here categorised five levels of urban salinity risk on a scale grading from low to very high and the level of management response varies accordingly.

Risk levels are lowest along the Gawler River where the watertable is deepest and risk levels are highest on the low lying portions of the site, particularly in the south and west. The extensive presence of clay material in the upper 4 m of the soil profile increases the salinity risk across the site due to the potential for perched watertables to develop. This is particularly pertinent to areas where clay is in the subsurface and is overlain by a more permeable material such as sand or silt that could act as an aquifer.

Where there is potential for perched groundwater to develop the installation of a subsurface drainage system should be considered. Management strategies must be concerned with maintaining groundwater at a safe depth below ground level and efficient water use practices to minimise groundwater recharge.

Proper design and verification of all proposed salinity management strategies is essential to successful urban development in areas at risk of urban salinity. The cost of a proper hydrogeological assessment prior to development would certainly be lower than that of the ongoing impact and remediation of salinisation.



1 Introduction

The Walker Corporation Pty Ltd engaged Resource & Environmental Management Pty Ltd (REM), now merged with Sinclair Knight Merz Pty Ltd (SKM), to investigate various groundwater issues as part of the preparation of an Environmental Impact Statement (EIS) for the proposed Buckland Park Country Township (Buckland Park). The development is situated 32 km north of Adelaide, adjacent to the Gawler River, west of Port Wakefield Road (Figure 1.1).

The potential groundwater issues associated with the Buckland Park proposal have been identified in the EIS guidelines prepared by the Development Assessment Commission. These issues, as provided to REM, can be arranged into the broad categories of shallow groundwater issues, contamination issues and Aquifer Storage and Recovery (ASR) potential.

This report primarily addresses the issues associated with shallow groundwater at the site. The content of this report is based on desktop work, field investigations and groundwater flow modelling using all available information. Analytical results from initial groundwater sampling are also reported, but issues relating to potential groundwater contamination have not been fully addressed in this report. The potential for an ASR operation at the site has been assessed and reported by REM in a separate document (REM, 2008).

1.1 Objectives

This report specifically addresses the following objectives:

- Description of the existing hydrogeological conditions affecting the site and its locality by undertaking a desk top study and detailed field survey.
- Description of the high unconfined water table(s) that exists in this area, including the predicted movement over the short and long term and the risk this represents to infrastructure, including housing stock.
- Identification of measures that could be applied to manage these risks (“...the high unconfined groundwater water table(s) that exists in this area”) in the short and long term.
- Description of measures to protect the Gawler River and coastal environments during operations.
- Description of the short and long term effects of constructing waterways for detention purposes on land and/or groundwater quality and movement, especially salinity.
- Description of any special engineering requirements for infrastructure due to the expected high water table in this area including the cost of developing and maintaining infrastructure for saline and acid sulphate soils, seasonal variations in height and groundwater rise due to sea level rise.
- Quantitative assessment of on-site groundwater hazards.



1.2 Scope of Work

The objectives of this report have been achieved through an assessment of existing information combined with new data collected from field investigations. The scope of work includes:

- Review of existing hydrogeological information;
- Installation of 11 new monitoring wells into the shallow watertable aquifer across the site;
- Hydraulic conductivity testing of all 11 new wells and 1 existing well to provide aquifer parameter data for inclusion in the groundwater flow modelling;
- Sampling of all 11 new wells for nutrients, major cations and anions and a broad contaminant screen;
- Mapping of groundwater depth, elevation and salinity across the development area using new data combined with data contained within existing databases (e.g. SA Geodata and Obswell). Groundwater depth was calculated as groundwater elevation subtracted from the available ground surface information.
- Description of the hydrogeology of the development area, including features and stresses that affect the level, salinity and movement of groundwater using new and existing information. Relevant features include those that currently exist such as drains and rivers and the proposed features such as new waterways.
- Assessment of seasonal and longer term trends in groundwater levels, to the extent possible using available time-series data, in order to assist in understanding potential threats to the proposed development.
- Inclusion of soil information obtained by Golder Associates during the geotechnical field program in the assessment of soil characteristics across the site;
- Estimation of changes to groundwater levels under the development scenario, taking into account changes to stormwater management and the increase in the paved area.
- Assessment of a range of potential activities associated with the proposed development to predict the impact of changes in land use on the shallow watertable aquifer and determine the impact of these changes on the watertable aquifer. Potential management measures will be assessed to rectify possible adverse impacts that may be identified.
- Assessment of groundwater elevation changes under the new development over time including an assessment of the impact of stormwater retention facilities.
- Assessment of a range of scenarios relating to groundwater levels (steady state conditions) associated with the development, including landscape options, impacts of wetlands and any need for sub-surface drainage.



- Provision of concepts for management responses in relation to the potential impacts of changes to shallow groundwater conditions on housing infrastructure, the Gawler River and coastal environment;



2 Data Review

2.1 Site Description

The site is situated to the west of Port Wakefield Road about 32 km north of Adelaide (Figure 1.1). The site covers around 1,308 hectares immediately south of the Gawler River.

Current land use in the area includes agricultural land (grazing and horticulture) with smaller portions of residential development and the Cheetham Salt evaporation ponds immediately to the west and south of the site.

The landscape is characterised as low lying and low relief coastal plain, as illustrated by the ground surface topography presented in Figure 2.1. Two natural watercourses (Gawler River and Thompson Creek) provide the majority of natural drainage. Prior to alteration, the drainage systems of the Gawler River (being the larger of the two watercourses) would have ended in a raised coastal delta formation within the mangroves and tidal flats which remain along the coast on the western boundary of the study area.

An overview of the physical characteristics of the land across the study area has been provided by Rural Solutions (2007). The higher land on the margin of north sector east, which sits at around 10-12 m AHD, is the tail end of a very gently inclined plain with sand to sandy loam topsoils over clayey subsoils. The system is underlain by alluvial sediments deposited by the Gawler River as it meandered across the plain. The sediments are mantled by aeolian carbonates. As the land drops below 10 m towards north sector west, saline groundwater tables begin to influence soil profiles and productivity potential. As the land further drops away to the low lying coastal flats and associated saline water courses the soils become poorly drained and the watertable is shallow and saline. In these areas the presence of land salinisation is recognisable either as saline subsoils or as surface seepage and the presence of salt tolerant vegetation.

2.2 Climate

The Adelaide coastal plain is characterised by a Mediterranean climate, with hot, dry summers and relatively cool, wet winters.

Local climate data has been sourced from the Bureau of Meteorology for the weather station on Sheedy Rd in Virginia, located approximately 2 km east of the Buckland Park site. This station was in operation during the period from 1889 through to 2005 and although it has now been closed, the data represent a long term climate record, spanning more than 100 years, that is situated very close to the present site. Annual rainfall totals and cumulative deviation from average annual rainfall are presented for the period of record in Figure 2.2 and mean monthly rainfall has been compared with mean monthly pan evaporation in Figure 2.3.

The average annual rainfall of 442 mm occurs mostly in the winter months with average monthly rainfall between June and August around 53 mm, in contrast to the months December to February with mean monthly rainfall around 22 mm.



The average annual pan evaporation of 1860 mm exceeds average annual rainfall by more than four times. On average during the winter months evaporation is approximately equal to rainfall, while during summer evaporation exceeds rainfall by around 12 times.

The record of cumulative deviation from the average annual rainfall (Figure 2.1) shows there have been a number of wetter and drier cycles over the last 100 years, with the most recent wet periods occurring in 2000 and then back in the mid 70's and again in the mid 50's. These wet periods correspond to years of above average rainfall.

2.3 Hydrology

The surface water hydrology of the Buckland Park area is largely controlled by the Gawler River situated immediately north of the site. The Gawler River extends across the northern and western boundary of the site. The ephemeral water course of the Gawler River can have large flows and flooding during the winter wet season but is largely dry, with only stagnant pools, during the drier summer months. The river channel has been incised below ground level by three to four metres. When flood flows break from the channel, flood waters will spill away from the channel towards lower lying areas. These flows generally do not re-enter the Gawler River channel.

Extending through the North Sector East and South Sector, Thompson Creek is a shallow intermittent ephemeral watercourse that channels surface flows during the wet season and periods of flooding when the Gawler River overflows. It is likely this watercourse also acts as a shallow groundwater drain when the shallow watertable is elevated above the creek bed as a result of direct recharge during the wet season.

The two salt lakes present immediately to the southwest of the site are currently operated by Cheetham Salt. A representative of Cheetham Salt, Mr. Kevin Taylor (*pers. comm.*, 22/2/2008), could not provide exact operational details for the lakes, but indicated the northern of the two lakes is held at a level of about 2.85 m AHD and the southern lake is held at about 3.25 m AHD. Mr Taylor also indicated the network of surface drains surrounding the lakes are intended to provide some management of the ingress of salt water onto the surrounding land. Survey data relating to the levels or inverts of the drains was not available, but Mr. Taylor did indicate to the north the drains discharge via pumping into the Gawler River channel. Flow gradients in the area are very low and Mr. Taylor suggested not a lot of flow occurs in the drains and the primary out flux was probably by evaporation.

2.4 Soils and Geology

In "Natural History of the Adelaide Region" (Royal Society of SA, 1976) Northcote describes the dominant soils of the study area as permeable, alkaline, red brown soils/calcareous red pedal clays with a moderate to high bearing capacity and deficiencies in nitrogen, phosphorous and zinc.

Reference to the Geologic Survey of South Australia – Adelaide 1:250,000 map sheet (DME, 1969) indicates the near surface stratigraphy of the study area comprises the Quaternary sediments of the Pooraka Formation, across the majority of the site, and the St Kilda and Glanville Formations towards the coast. The Pooraka Formation is described as mottled clay and silt inter-bedded with sand, gravel and thin sandstone layers. The St Kilda formation is characterised by estuarine muds, sands, peats and shelly beds and often contains lenses of highly permeable sand layers.



The Late Quaternary sediments on the Northern Adelaide Plains overlie the older sediments of the Hindmarsh Clay, which is described as a layered sequence of mottled red-brown sandy clay and sand and gravel lenses. In a hydrogeological context these units can together be collectively described as clays containing lenses and discontinuous layers of silts, sands and gravels.

Interpretation of available lithological logs and drillers logs from the state Drillhole Enquiry System (DES) (locations shown on Figure 2.4) indicates the near surface sediments comprise discontinuous beds and lenses of clay, silt and sand. In a similar fashion to the site specific data, presented below, there is a high degree of variability in the logged sediments both laterally across the area, and vertically through the profile. However, it also became evident interpretation of the data is confounded by a lack of detail in the near surface interval in many of the logs. A geological cross-section, based on the logs from DES (Figure 2.5) illustrates the variability from west to east across the site (location shown on Figure 2.4), but also seems to indicate a relatively consistent clay layer sitting at a depth of around 20 metres across the site.

2.5 Shallow Aquifer Sequence

The uppermost groundwater aquifers across the study area occur in the sand and gravel lenses of the Pooraka, St Kilda and Hindmarsh Clay Formations. While it appears these thin shallow aquifers are often discontinuous it has also been suggested (REM, 2002) the top Quaternary aquifer (Q1) is hydraulically connected with aquifers within the marine sediments of the St Kilda Formation forming a somewhat continuous aquifer system (and pathway) across the study area.

According to Martin and Hodgkin (2005), a shallow Quaternary aquifer is present in the area between Virginia and Gawler River. Wells to monitor this perched aquifer have been drilled to depths of between 2.5 and 9.5 m, but most commonly wells are completed at 4-6 m depth (Rural Solutions, 2007). According to AGT (2004), pumping test results for two sites close to Buckland Park showed this perched aquifer can be hydraulically connected to the underlying Q1 aquifer, while the Q1 aquifer and underlying Q2 aquifer had almost no hydraulic connection. Three Quaternary aquifers (Q1 to Q3) are generally recognised in the Northern Adelaide Plains region with thicknesses ranging from about 3 to 15 m. They can be quite discontinuous with lateral extents of less than 2,000 m. Overall, the thickness of the Hindmarsh Clay diminishes northwards and can be as little as 20 to 30 m near the northern limit of the Northern Adelaide Plains Prescribed Wells Area (PWA). Clay generally underlies the Q3 aquifer and forms a confining bed, although there are localised occurrences where the Q3 aquifer is in hydraulic continuity with the underlying aquifer.

A report produced by Rural Solutions SA (Rural Solutions, 2007) covering the nearby Virginia area provides information on aquifer delineation within the Quaternary sequence. According to that report, the unconfined Q1 aquifer, uppermost in a series of sandy layers in the Hindmarsh Clay, comprises thin layers of silt and sand at depths of around 5 to 10 m, although wells have been drilled to depths of up to 17 m to delineate the Q1 aquifer. To delineate the Q2 aquifer wells have been drilled to depths of between 13 and 28 m.

2.6 Groundwater Levels and Trends

Available existing data on groundwater levels in the watertable aquifer were obtained from the DWLBC database. These data, also assessed by REM (2002) showed water levels are typically quite shallow, at



between around 1 to 6 m below ground level (bgl). Shallow groundwater occurs particularly in low lying areas and where clay layers cause perching. There was generally a decreasing trend in groundwater levels from the higher land to the north east towards the coast in the southwest. The available historical data was rather sparse, but some time series information was found. The locations of the few wells with time series data are shown in Figure 2.6. The data from these wells has been plotted up and an example is presented in Figure 2.7. Plots of the data from all the wells are attached in Appendix A. This information shows what appears to be a seasonal fluctuation in water levels, indicating diffuse rainfall recharge of the shallow aquifer. However, with rainfall amounts being quite variable in this region the seasonal fluctuations are somewhat less than regular. Seasonal watertable fluctuations appear to be in the order of around 1 to 2 m, obviously depending on the amount of seasonal rainfall.

2.7 Groundwater Salinity

The shallow groundwater is generally quite saline, but according to existing information assessed by REM (2002), salinity can range widely from almost potable (1,280 mg/L) to around that of sea water (30,000 mg/L). Typically fresh groundwater occurs where localised recharge has occurred from a surface water source such as river losses or excess irrigation water. Groundwater in much of the area is quite shallow and, particularly in low lying areas, evaporative processes are active in concentrating salts in the shallow watertable aquifer.

2.8 Data Gaps and Project Approach

The availability of hydrogeological information within the Buckland Park study area was limited prior to the field investigation programs undertaken as part of this project. The nearby Virginia area has been much more intensively investigated in the past due to the high level of activity there, but to the west of the Port Wakefield Road there has been much less activity and available stratigraphic and hydrogeological information is scattered and sparse.

The geological layering in the project area, particularly in the Quaternary sediments, appears to be highly variable. Soil type varies widely both spatially and with depth through the profile and as a result it does not appear to be possible to construct an obvious 'layer cake' of the profile clearly represents the sequence of aquifers and aquitards beneath the area.

A field investigation program has been undertaken to support the analysis and provide additional information with which to understand the subsurface conditions. Lithological information and groundwater level and groundwater quality information were obtained from the drilling and installation of 11 groundwater monitoring wells by REM. Additional soil information was obtained from site investigations undertaken by Golder Associates and Connell Wagner as part of the EIS-related investigations, and groundwater level data were obtained from the 15 wells installed by Connell-Wagner.

While some historical groundwater level monitoring data was found for a few wells on or near some parts of the study area, the distribution and extent of the available time series information was not sufficient to support the development of a transient state groundwater flow model for the site. Rather it was considered more useful within the project framework to focus on the development of a steady state groundwater flow model and achieve model calibration using available existing information combined with newly generated



groundwater level information. This model can still be used to assess relative potential changes to groundwater conditions at the site from a range of scenarios associated with the development.

A qualitative analysis of the likely transient behaviour of the groundwater system has been included in this assessment from interpretation of the few available water level hydrographs.



3 Groundwater Investigation Program

3.1 Approach

To provide the additional data necessary to develop an understanding of the shallow subsurface conditions present at the Buckland Park site and to allow testing of shallow groundwater for the presence of contamination, additional groundwater monitoring wells were required. Eleven new groundwater monitoring wells were installed to depths ranging from 10 m in the northeast of the site to around 3.5 m in the southwest, to screen the shallow watertable aquifer. The locations of these new wells, as shown on Figure 2.4) were chosen to complement existing monitoring wells in the area and to provide an even distribution across the site.

This section describes the methodology for well installation, sampling and aquifer testing and the laboratory analysis and reference criteria for the analytical data.

3.2 Monitoring Well Installation

Solid flight augers were utilised for the drilling of all groundwater monitoring wells. Due to the sandy nature of the water table aquifer in some areas three of the wells were installed with spear-point end caps and filter sock covering the screened interval. All drilling equipment was thoroughly cleaned before the commencement of drilling and between sites to minimise the potential for cross-contamination between locations.

Well construction details for all new groundwater monitoring wells installed by REM are presented in Table 3.1. Each new groundwater monitoring well was constructed using DN 50 mm Class 18 uPVC with screen intervals varying from 3 m to 4.5 m. The annular space between the well screen and the borehole wall was backfilled with clean, washed, well graded, predominantly silica sand (filter material) of a size compatible with the screened geological unit so no significant loss of filter material from the well annulus occurred during development. A bentonite seal and cement grout was placed above the filter material extending up to the ground level. The wells were then completed at the surface with a lockable cap and lockable standpipe set into a concrete pad.

Well materials were supplied by the drilling contractor. All materials were new and undamaged. All equipment and materials (except for new materials such as sand and cement grouts) were decontaminated and stored in a fashion that provided adequate protection from contamination or damage prior to use.

Drilling and installation of all groundwater monitoring wells was supervised by a qualified REM hydrogeologist. The lithological logs and well construction details for the newly installed wells are provided as Appendix B along with the well construction permits in Appendix C.

All new monitoring wells installed by REM were surveyed to the Australian Height Datum (AHD) by Connell Wagner as part of their involvement in the project. Groundwater level data were reduced relative to AHD and used to produce groundwater elevation contours and assess flow directions.

In addition to the wells installed by REM, 15 more groundwater monitoring wells were installed by Connell Wagner on 16-18 April 2008 and the resulting soil and water level information collected from these wells has also been included in this assessment.



3.3 Groundwater Sampling

Groundwater monitoring wells MWREM03, MWREM04, MWREM06, MWREM07, MWREM08, MWREM09, MWREM11 and MWREM12 were sampled on the 7 February 2008. However, some samples were lost en-route to the analytical laboratory so re-sampling of some wells occurred as part of the second day of sampling activities. The remaining three groundwater monitoring wells, MWREM01, MWREM02, MWREM05, were sampled on 13 February 2008 along with re-sampling of MWREM04, MWREM06, MWREM08 and MWREM11 for selected analytes. Groundwater levels at each location were recorded prior to disturbance using an electronic water level probe.

All monitoring wells were purged of at least three bore volumes, or purged dry using dedicated disposable bailers prior to sampling. The purging process ensures the groundwater sample collected is representative of groundwater in the aquifer at that location. Field chemical parameters were recorded after each bore volume was removed to ensure stable geochemical conditions existed prior to the collection of the groundwater sample. The pH, redox, electrical conductivity and temperature meters were calibrated prior to the commencement of purging.

Groundwater purge sheets are presented in Appendix D.

Groundwater samples were placed in laboratory cleaned bottles containing appropriate preservatives, and then placed into a chilled esky for transport to the Australian Laboratory Services, a National Association of Testing Authorities (NATA) registered laboratory. Duplicate groundwater samples were also collected and sent to Labmark Environmental Laboratories, another NATA registered laboratory. Groundwater samples analysed for metals were filtered in the field using dedicated 0.45 micron filter for each sample and were placed into pre-acidified containers.

3.4 Aquifer Hydraulic Testing

To provide information on aquifer hydraulic conductivity within the study area, slug recovery tests were carried out by REM on the eleven newly installed monitoring wells and one existing well at the site. Rising head slug tests were undertaken by instantaneously removing a slug of water from the tested well using an inline submersible pump and dedicated WATERA tubing for each well. Water level recovery in the well was recorded, using an In-Situ Inc. miniTROLL down-hole pressure transducer, to within 5% of the pre-pumping standing water level. Data were recorded electronically on a laptop computer, at 0.5 or 1 second intervals, as pressure in pounds per square inch above the transducer. The raw data were later transformed into depth to water in the well using a two-step process. A calculation was applied to give the height of water column in the well, using the approximate groundwater salinity, and then the data were adjusted using the known (measured) depth to water at the completion of the test as a reference point.

Analysis of the rising head slug test data was undertaken using the Bouwer-Rice method (Bouwer and Rice, 1976) to determine horizontal hydraulic conductivity of the aquifer in the vicinity of each well. This approach is suited to partially penetrating wells in which the water level falls below the top of the screened interval. In addition to the water level drawdown data, input parameters included well casing diameter of 50 mm ID, drill-hole diameter of 125 mm and the total depth and screened interval of the wells.



The aquifer testing analysis sheets, used to calculate hydraulic conductivity from the test results, are provided as Appendix E.

3.5 Analytical Laboratory Program and Criteria

Groundwater samples were analysed for nutrients, major cations and anions and a broad contaminant screen including 13 metals, total petroleum hydrocarbons (TPH), benzene, toluene, ethylbenzene and xylene (BTEX), polycyclic aromatic hydrocarbons (PAH's), organochlorine pesticides (OCP's) and phenoxyacetic acid herbicides.

Groundwater at the site ranges in salinity from almost potable through to more saline than seawater and potential receivers of this groundwater include the Gawler River and the marine environment. In this context, the groundwater analytical results from the site have been compared to the following guidelines:

- SA EPA (2003) Environment Protection Policy - for Potable, Irrigation and Livestock uses
- SA EPA (2003) Aquatic Ecosystems - both Fresh and Marine waters
- ANZECC (2000) – Marine Water Quality; and
- MHSPE, 2000 Dutch Intervention Criteria (adopted where no alternative guideline was available).



4 Site Investigation Results

4.1 Site Soils and Geology

Drilling logs were produced by REM from the installation of 11 groundwater monitoring wells to depths ranging from about 10 metres near the Gawler River to about 3.5 metres in the lower lying areas in South Sector West. In addition, logs were obtained from Golder Associates, covering depths of 3 to 6 metres, and from Connell Wagner, covering depths of 6 to 9 metres. Existing information from the Department of Water Land and Biodiversity Conservation (DWLBC) online Drillhole Enquiry System (DES) was also incorporated in this assessment.

This lithological information indicates a near surface geology that is highly variable both across the study area and with depth through the profile. Sediment composition included sand, silt and clay in varying proportions, but in general an abundance of clay and clayey sediments were identified across the site. Sand and silt appeared to be present in lenses and pockets that were not spatially continuous across the site. In the majority of holes an appreciable thickness of clay was present at or near the surface. In order to illustrate the spatial distribution of clay across the site, and the relative levels at which it occurs, a map of depth to clay (Figure 4.1) was produced from all available lithological logs. This interpretation shows that clay is likely to be present in the upper 4 m of the soil profile across nearly the entire site, and there are large areas where clay is at the ground surface. The few areas where clay is deeper than 4 m are isolated and mostly associated with only one or two data points.

The data shows that subsurface clays occur extensively throughout the study area at depths of less than 4 m bgl. These clays will act as an impediment to downward movement of water and, in the case where they are overlain by more permeable sediments like sand or silt, there is potential for development of shallow perched watertables to develop.

For practical purposes, the soil profile relevant to the watertable aquifer system is assumed to extend to around 20 m bgl. This assumption is based on the more regional interpretation of lithological information presented in cross section in Figure 2.5. Below this depth the extensive occurrence of clay across the region is assumed to act as an aquitard separating the surface system from the deeper confined aquifers.

It should be noted that drill holes completed in this study were targeting either the groundwater table (REM and Connell-Wagner holes) or the shallow soil composition (Golder Associates), so the resulting lithological information covers only a portion of the profile associated with the upper Quaternary sedimentation and shallow aquifers. In particular, holes in North Sector East extend to near 10 metres, while those in South Sector West extend to only 3.5 metres.

4.2 Site Hydrogeology

4.2.1 Groundwater Levels and Flow Direction

Groundwater level gauging of new and existing monitoring wells has been undertaken by REM, using an electronic dip meter, on five separate occasions as part of this investigation (Table 4.1). Initial water level gauging of available existing wells took place during REM's initial site visit on 8 January 2008 and during new monitoring well installation works on 15 January 2008. Gauging of all newly installed REM wells took place on 7 February 2008, followed by repeat gauging of all new REM wells and one existing



well during groundwater sampling activities on 20-21 February 2008. Following installation of the additional wells by Connell Wagner, further rounds of water level gauging was undertaken by REM on 2 July 2008 and 2 October 2008, including all new and available existing wells.

The results of groundwater level gauging from 7 February 2008 showed the elevation of the watertable beneath the site ranging from a low of 1.38 m AHD in MWREM08, situated in the southernmost and lowest point of the site, to a high of 6.40 m AHD in MWREM01, situated in the northernmost and highest point of the site. As with most areas, the watertable elevation and groundwater flow direction across the study area generally mimics the shape of the land surface dropping down towards the coast. Groundwater elevations vary from around 8 m AHD immediately northeast of the site to 0 m AHD at sea level not far to the southeast and east of the site.

Groundwater elevation contours interpreted from the 7 February 2008 data (Figure 4.2) the 2 July 2008 data (Figure 4.3) and the 2 October 2008 show that groundwater flow occurs in a general westerly and south westerly direction towards the coast. Comparison of the sets of data show some minor changes in watertable elevation, but all of the main features of the groundwater flow pattern across the study area are essentially the same. This provides an improved level of confidence in the data. Two areas of groundwater mounding were quite well defined by the data. The first area is situated in the vicinity of wells MWREM04, MWREM06 and GW2. The cause of more elevated groundwater levels in this area is not clear, but it may be associated with historic or current irrigation practices in that area. The second area is situated in the vicinity of well 6628-20004, which is completed at a depth of 3 m bgl. Groundwater mounding at that location is more obviously caused by roof runoff and possibly excess irrigation from adjacent glass house horticulture. This well is nested with an 8 m deep well, which recorded a water level of 1 - 2 m lower than the shallower well. This indicates that a perched watertable has developed in sediments on top of a shallow low permeability clay layer in this area. At this site REM personnel observed that downpipes channelled runoff from the glass house roofs to an area right next to the nested shallow wells. It seems likely that this localised source of recharge has affected the shallow groundwater levels in this area. While this water level data point has been included in the interpretation of groundwater elevation contours across the study area, it might have unduly influenced the interpretation of water levels in the surrounding area, causing groundwater mounding to appear more extensive than is actually the case.

The hydraulic gradient across the site varies between about 1 to 2 metres per kilometre (0.001 to 0.002) and is controlled by factors including hydraulic conductivity of aquifer materials, recharge, surface drainage and topography. The hydraulic gradient is somewhat steeper across the eastern part of the site and this could be due to factors including steeper surface topography, variable hydraulic parameters and/or higher recharge from irrigation activities.

Local variations to the shallow groundwater flow not picked up in this monitoring data might occur close to hydrological features including rivers and drains and near the salt lakes where groundwater mounds exist. Due to the elevated pool levels in the salt lakes immediately to the southwest of the site, it is likely that over time water from the salt lakes has seeped through the beds and caused mounding of shallow groundwater in that vicinity. However, during construction of the salt lakes a system of groundwater drains surrounding the lakes was also installed, in an attempt to manage the effects of groundwater



mounding on the surrounding land. These drains are supposed to collect seepage water and channel it into the natural drainage that discharges to the sea. In reality it would appear that flow gradients are so slight in that low lying area that most water discharge occurs as evaporative out-flux from the open drains and from shallow groundwater tables.

A reduction in the groundwater flow gradient towards the coast is evident in the interpreted watertable elevation contours, but specific hydraulic effects of the elevated pool levels in the salt lakes are not apparent in the available data.

4.2.2 Depth to Groundwater

The results of groundwater level gauging undertaken by REM reveal that the groundwater table is quite shallow, at less than 4 m, across the majority of the site. Depth to groundwater, measured on 7 February 2008 in the 11 new wells installed by REM (Table 4.2), ranged from 0.88 m bgl in MWREM07, situated in the low lying south sector west, to 5.67 m bgl in MWREM03 situated on the higher ground adjacent to the Gawler River along the northern boundary of the site. A subsequent round of water level gauging on 2 July 2008 (Table 4.2) showed minimal change at MWREM07 and a fall in the watertable at MWREM03 to 5.82 m bgl.

Mapping of depth to groundwater across the study area, covering all points in between the measured points obtained from groundwater gauging activities, was achieved by subtracting an interpolation of groundwater elevation from the ground surface elevation. This method minimises the error in the interpretation of groundwater depth because it accounts for the variability in the ground surface in addition to spatial trends identified in gauging data. However, it must be stressed that while the groundwater data is valid for the current situation, future changes to groundwater levels may occur that would require periodic updates to the data set.

Interpreted groundwater depth across the study area is presented in Figure 4.5, for the 2 July 2008 water level gauging event. This information shows a broad gradient in depth to groundwater, with deepest levels along the Gawler River to the north, and also highlights the fairly extensive occurrence of shallow groundwater (less than 4 m depth) across much the site, particularly along the south, east and west perimeter. The watertable could be less than 4 m bgl across much of the central sector, south sector and south sector west of the site. The occurrence of shallow groundwater is strongly controlled by the surface topography, with these areas occurring in the lower lying places and natural or artificial depressions in the landscape. The land along the Gawler River, in the north sector east and north sector west, is the only portion of the site where groundwater is likely to be deeper than about 4 m bgl. A spur of higher ground extending down the southwest of the site increases the depth to groundwater in that area slightly.

Problems associated with water logging and salinity are most likely to occur in areas where the depth to groundwater is less than 2 m bgl. This hazard is independent of whether the shallow groundwater is in the regional watertable aquifer or in a more localised perched aquifer sitting on top of a low permeability clay layer. The latter occurrence is typically of most concern when the top of said clay layer occurs within the top 4 m of the soil profile.



4.2.3 Hydraulic Aquifer Characteristics

Aquifer testing was undertaken on 20 - 21 February 2008 to provide aquifer property data for input to the numerical groundwater flow model. Water level recovery tests were conducted on the eleven newly installed wells MWREM01 thru MWREM09 and MWREM11 and MWREM12 plus one existing well with the state database Observation Number PTA058.

Hydraulic conductivity values are presented in Table 4.3. Values range from 0.01 to 1.12 m/day. Lower values are reported along the Gawler River where values of 0.01 and 0.07 m/day were recorded for bores MWREM01 and MWREM07 respectively. These are the lowest values on site with the other value of similar magnitude (0.06 m/day) occurring at MWREM09. Slightly more elevated values occur along the southern boundary (0.12 m/day at MWREM07, 0.18 m/day at MWREM08 and 0.19 m/day at MWREM12. Remaining wells have still slightly higher values of hydraulic conductivity but all of the wells tested display low hydraulic conductivities.

The information provided by the slug recovery testing on the shallow wells installed by REM provides perhaps an overly conservative indication of the permeability of near surface sediments across the study area. It is recognised that the wells were installed mainly to enable monitoring of groundwater levels and, as such, they do not fully penetrate the watertable aquifer. In many cases the well screen penetrates only partially into sandy sediments that were encountered. Therefore it is quite likely that the resulting permeability values obtained from these wells are an underestimation of the actual values of this parameter for the watertable aquifer system. Based on experience it is possible that actual aquifer permeability values could range from around 0.01 m/d for clayey sediments up to around 10 m/d for coarser sandy sediments.

4.3 Groundwater Analytical Results

Groundwater analytical results are presented in Table 4.4 and laboratory analytical reports are contained in Appendix F.

4.3.1 Field Parameters

Field parameters (Table 4.5) measured during the groundwater sampling program, which was undertaken on 7 February and 13 February 2008, indicate the following hydro-geochemical conditions exist in groundwater sampled from wells across the Buckland Park site:

- pH values range from 6.66 at MWREM06 to 7.97 at MWREM09. Groundwater was generally neutral to slightly alkaline. Groundwater sampled from MWREM06 and MWREM07, at the low lying southwest end of the site, was slightly acidic.
- Electrical conductivity of sampled groundwater ranged from 5.02 mS/cm at MWREM09 to 106.6 mS/cm at MWREM06.
- Temperature of sampled groundwater ranged from 18.7 °C at MWREM11 to 23.2°C at MWREM06.

4.3.2 Groundwater Salinity

The salinity of sampled groundwater from the Buckland Park site has been estimated, as total dissolved solids (TDS), from field measurements of groundwater electrical conductivity (EC). This approach has



been adopted in favour of using the sum of cations and anions from the analytical laboratory data because the charge balance error was in excess of acceptable limits.

The simple linear relationship reported in Hem (1985) was used to convert field measured EC in mS/cm into TDS in mg/L, by applying a multiplication factor of 750. In natural waters this multiplication factor commonly ranges between 550 and 750, with the higher values generally being associated with water high in sulphate concentration. Perusal of the analytical data for sampled groundwater from Buckland Park shows high sulphate concentrations for many of the samples, thus the higher multiplication factor was used.

The salinity of groundwater samples collected from the new wells installed by REM (Table 4.5) ranged from a relatively fresh 3,765 mg/L at MWREM09 to a hyper-saline 79,725 mg/L at MWREM07 and 79,950 mg/L at MWREM06. Both of these hyper-saline wells are situated adjacent to the salt lakes in the low lying southwest corner of the site.

When combined with available data from existing nearby wells this information provides a good indication of the spatial variability of the salinity of shallow groundwater across the study area. As shown in Figure 4.6, groundwater salinity is broadly more saline in the west and fresher to the east. Some notable features of the groundwater salinity data include the following points:

- The salinity of groundwater in MWREM09, located centrally in the south sector west, was measured at 3,765 mg/L, which is much fresher than that of surrounding nearby wells. This is an area that is suspected to have been subject to historic irrigation, and it is postulated that the lower salinity correlates to a lens of fresh water remaining from the historic irrigation.
- The salinity of groundwater in MWREM05, measured at 18,450 mg/L, was significantly higher than that of other nearby wells. Field observations made by REM staff and interpretation of the site aerial photo suggest that this well is adjacent to clay pans and a natural depression where water tends to pond. It is likely that groundwater in this area is subject to a higher rate of evaporative discharge and subsequent concentration of salts in groundwater.
- At sites where data from nested monitoring wells is available, the groundwater in the shallower well is usually much fresher than that in the deeper well. This suggests that perched groundwater does occur in some areas of the site and it is likely that this water originates from drainage of excess irrigation water. Thus it follows that perched groundwater would typically be expected in areas where such irrigation practices are in effect.

4.3.3 Analytical Laboratory Data

4.3.3.1 Major Ions

Major ion chemistry data showed that the sampled groundwater at Buckland Park was generally very saline (average TDS of 28,930 mg/L), and the ionic composition of the groundwater samples was dominated by sodium and chloride, as is usual for most natural waters, but a significant proportion of sulphate was also present in most samples.

Sulphate concentrations exceeded the SA EPA (2003) guideline value for Livestock use of 1000 mg/L in samples from seven of the eleven wells across the site. The highest levels of sulphate occurred in wells



MWREM06 (6,990 mg/L), MWREM07 (9,820 mg/L) and MWREM08 (3,390 mg/L) all of which are situated in the hyper-saline area adjacent to the salt lakes. Other samples with sulphate levels of 1000 to 3000 mg/L were from MWREM03, MWREM04, MWREM05, MWREM08 and MWREM12.

Sulphate concentrations exceeded the SA EPA (2003) guideline value for Potable use of 500 mg/L in samples from ten of the eleven wells across the site. In addition to the wells listed above for exceeding the Livestock value, samples from wells MWREM01, MWREM02 and MWREM11 exceeded the Potable guideline value, with sulphate concentrations from 731 to 981 mg/L.

The ionic balance errors for MW3, MW9, MW12 and MW6 were reported to be greater than the 5% target amount due to analytes not quantified in the reported analysis. This is a limitation to the confidence that can be placed in the major ionic composition of these samples, but does not affect the validity of other samples or analytes. Re-sampling and analysis of major ion chemistry and TDS would enable a more accurate determination of the cation and anion composition of these samples.

4.3.3.2 Fluoride

Fluoride concentrations were reported for field duplicate samples analysed by Labmark. Fluoride concentrations exceeded the SA EPA (2003) guideline value for Livestock use of 2 mg/L in MWREM07 (3.2 mg/L). Fluoride concentrations also exceeded SA EPA (2003) guideline values for Irrigation use of 1 mg/L in MWREM11 (1.3 mg/L).

4.3.3.3 Nutrients

Groundwater analytical results for nutrients identified the following:

- Ammonia concentration exceeding the SA EPA (2003) Aquatic Ecosystem (Fresh) guideline value of 0.5 mg/L was reported in groundwater sampled from MWREM06 (0.61 mg/L). In addition, ammonia concentration exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) guideline value of 0.2 mg/L was reported in groundwater sampled from MWREM06 (0.61 mg/L) and MWREM07 (0.43 mg/L).
- Nitrate concentration exceeding the SA EPA EPP (2003) Water Quality (Potable Use) guideline value of 10 mg/L was reported in groundwater sampled from MWREM02 (23.4 mg/L).
- Total nitrogen concentrations exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) guideline value of 5 mg/L were reported in groundwater sampled from MWREM02 (26.4 mg/L), MWREM04 (7.4 mg/L), MWREM08 (5.6 mg/L) and MWREM11 (5.0 mg/L)
- Total phosphorous concentrations exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) guideline value of 0.5 mg/L were reported in groundwater sampled from MWREM01 (0.57mg/L), MWREM04 (0.97 mg/L), MWREM07 (0.5 mg/L) and MWREM08 (1.39 mg/L).

4.3.3.4 Metals

Groundwater analytical results for heavy metals identified the following:

- Chromium concentrations exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) Chromium VI guideline value of 0.0044 mg/L were reported in groundwater sampled



from MWREM05 (0.005 mg/L), MWREM07 (0.014 mg/L) and MWREM09 (0.005 mg/L).

- Copper concentrations exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) Copper guideline value of 0.01 mg/L were reported in groundwater sampled from MWREM06 (0.016 mg/L), MWREM07 (0.04 mg/L) and MWREM08 (0.011 mg/L)
- Lead concentrations exceeding the SA EPA (2003) Potable Water use guideline value of 0.01 mg/L were reported in groundwater sampled from MWREM06 (0.014 mg/L) and MWREM07 (0.123 mg/L).
- Manganese concentrations exceeded the SA EPA (2003) Irrigation use guideline value of 2 mg/L were reported in groundwater sampled from MWREM01 (8.55 mg/L).
- Nickel concentrations exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) guideline value of 0.015 mg/L were reported in groundwater sampled from MWREM01 (0.016 mg/L), MWREM06 (0.015 mg/L) and MWREM08 (0.015 mg/L).
- Zinc concentrations exceeding the SA EPA (2003) Aquatic Ecosystem (Marine) guideline value of 0.05 were reported in groundwater sampled from MWREM06 (0.302 mg/L) and MWREM07 (0.071 mg/L).

Three of the eleven samples analysed for chromium showed levels elevated above the SA EPA criteria for chromium VI in marine aquatic ecosystems. However, in the absence of specific industrial activities that generate chromium VI, chromium in the environment occurs as the relatively benign chromium III species. It is likely that the small amount of chromium detected in some of the samples from the Buckland Park site is the latter chromium III species.

4.3.3.5 TPH and BTEX

The SA EPA does not nominate a limit for TPH under Potable, Irrigation, Livestock or Aquatic Ecosystem guidelines. Dutch Intervention Levels state a limit of 600 µg/L for Total C10-C36. All samples analysed from the Buckland Park site were returned at levels below this standard.

Groundwater sampled from all but two bores reported levels of BTEX below detection limits. Those samples that did report BTEX components at detectable levels were well below SA EPA (2003) standards for Potable Water, Aquatic Ecosystems (Marine) or Aquatic Ecosystems (Fresh).

4.3.3.6 PAH's

The PAH criteria value specified by the SA EPA is known to be the limit for benzo-a-pyrene. No other values are specified. The laboratory standard detection limits of reporting for PAH's are higher than this SA EPA guideline value and higher than some of the ANZECC (2000) and Dutch Intervention Levels values but all samples analysed from the Buckland Park site came back at below the laboratory standard detection limit of reporting.

4.3.3.7 OCP's

Similarly, all samples analysed for organochlorine pesticides came back at below the laboratory standard detection limits of reporting, although for some individual analytes this limit was above the available guideline value.



4.3.3.8 Phenoxyacetic Acid Herbicides

The SA EPA does not nominate a limit for PAH under Potable, Irrigation, Livestock or Aquatic Ecosystem guidelines. Dutch Intervention Levels state a limit of 50 µg/L for MCPA. All samples analysed from the Buckland Park site were returned at levels below this standard.

4.3.4 Analytical Data Quality

The quality of analytical data produced for this project has been assessed with reference to the following issues:

- sampling technique;
- preservation and storage of samples upon collection and during transport to the laboratory;
- sample holding times;
- analytical procedures;
- laboratory limits of reporting;
- field duplicate agreement;
- laboratory quality assurance/quality control (QA/QC) procedures; and
- the occurrence of apparently unusual or anomalous results.

Laboratory QA/QC procedures and results are detailed in the certified laboratory results contained in Appendix F. A summary of the data quality assessment and a summary of the field duplicate sample relative percentage differences are included as Appendix G.

All samples were collected, stored and transported to the laboratory in accordance with standard REM protocols which are consistent with the requirements of Schedule B(2) of the NEPM (NEPC,1999). Laboratory analysis was undertaken within specified holding times and in accordance with National Association of Testing Authorities (NATA) accepted analytical procedures and the requirements of Schedule B(3) of the NEPM (NEPC,1999).

Laboratory quality control information indicates an acceptable degree of QA/QC information was collected and reported and the data provides confidence in the accuracy and precision of reported results.

Relative Percentage Differences (RPD's) were elevated for a range of analytes in some samples. The discrepancy is not considered significant in the interpretation of the results as the results were either close to the limit of reporting where precision is somewhat comprised or the absolute differences between reported concentration results were quite small. The remaining elevated RPD% of field duplicates were within acceptable limits giving confidence to the values reported by the primary laboratory.

Overall, the accuracy and precision of analytical data is considered suitable to form a basis for interpretation of results for the purposes of this assessment.



The Limit of Reporting (LOR) for some analytes in some samples was increased due to matrix interference as a result of high sample salinity. Increased LORs occurred for Ammonia, Metals and Phenoxy Acid Herbicides.

Three intra-laboratory duplicates (MW2, MW7 and MW11) and two inter-laboratory duplicates (MW7 and MW11) were undertaken as part of the sampling activities. For MW11 the primary and intra-lab duplicate samples were lost en-route to the lab for all analytes except TPH and BTEX. Two intra-lab duplicates and one inter-lab duplicate have therefore been reported, with the exception of TPH and BTEX for which all duplicates undertaken have been reported.

Elevated RPD's were identified between the primary (ALS) and the intra-laboratory duplicate (ALS) and the inter-laboratory duplicate (Labmark) for the following analytes:

- Nitrate between the primary and intra-lab duplicate samples for MW7. However, the detected concentrations are close to the LOR and are well below the relevant guideline values for nitrate.
- Total phosphorous between the primary and the intra-lab duplicate samples for MW2, however, the detected concentrations are close to the LOR so the actual exceedance is considered marginal. Total phosphorous between the primary and inter-lab duplicate samples for MW7, however, the exceedance is considered relatively small and neither value exceeded any of the relevant guideline values.
- Reactive phosphorous between the primary and the intra-lab duplicate samples for MW7, however, the exceedance is marginal and the reported values are close to the LOR and well below the relevant guideline values.
- Lead between the primary and intra- and inter-laboratory duplicates for W7. The intra- and inter-laboratory samples are more similar to, and considerably lower than the primary sample, thus placing the validity of the primary sample into question. It is likely that the actual lead concentration is lower than the value reported for the primary sample.
- Zinc between the primary and inter-lab duplicate samples for MW7. Also zinc between the primary and intra-lab duplicate samples for MW2.
- Toluene between the primary and intra-lab duplicate samples for MW2. However, the reported values are near or below the LOR and well below the relevant guideline value.

4.4 On-going Investigations: Nutrient and Contaminant Impacts

Further works are currently being undertaken to determine sources of potential nutrient and contaminant impact to groundwater within the site. Further works are also being undertaken to assess nutrient and contaminant levels in groundwater from the existing groundwater monitoring wells. The results and findings of these works will be reviewed by SKM's Victorian EPA Environmental Auditor (Contaminated Land), Mr Don McCarthy who will also prepare the necessary technical responses to the Development Assessment Commission in relation to the questions previously posed with respect to contaminant and nutrient loads and any risk(s) to the receiving marine environment.



5 Numerical Groundwater Flow Model

5.1 Overview

A numerical groundwater flow model was constructed based on available existing information and new information generated from site specific field investigations as part of this project. The model was calibrated in steady-state to measured groundwater levels across the site and surrounding nearby area.

The numerical model was designed to examine the effect of changes to the shallow watertable as a result of Buckland Park construction and activities.

5.2 Conceptual Hydrological Model

The conceptual model for the site hydrogeology is based upon interpretation of available geological and hydrogeological information including bore logs and groundwater level data. New information provided by the installation of groundwater monitoring wells and aquifer testing data has formed an important part of the conceptual model development.

5.2.1 Aquifer Structure

The shallow groundwater system exists in Quaternary aged sediments associated with alluvial outwash deposits. Sediments comprise discontinuous beds and lenses of clay, silt and sand, with clay being the dominant soil type across most of the study area. The shallow groundwater system is assumed to be hydraulically continuous laterally, although with varying degrees of permeability. The modelled sequence is assumed to have a nominal thickness of 20 m, with the extensive occurrence of underlying clayey material acting as an aquitard.

Groundwater occurs variably in sand lenses between more clayey sediments and this may occur at multiple levels in the vertical dimension at any given location. However, these lenses of more permeable sediments are not continuous across the study area. In the context of this modelling exercise, it was not realistic to attempt to fully define the soil lithology in three dimensions. Rather, the 20 m thick profile was nominally divided into the three layers of 0 – 5 m, 5 – 10 m and 10 – 20 m bgl. The available lithological logs for the study area were then simplified by assigning a dominant soil type to each of these three intervals, as shown in Figures 5.1, Figure 5.2 and Figure 5.3. A spatial interpretation of the dominant soil types for each layer was then used to define the soil hydraulic properties in the groundwater flow model.

5.2.2 Groundwater Flow

The general groundwater flow pattern across the study area generally mimics the shape of the land surface dropping down towards the coast. Groundwater flows from the higher land in the southeast and east toward the coast to the southwest and west. Groundwater flow is controlled primarily by the permeability of the aquifer and recharge and discharge processes. Local variations in the flow pattern can occur in areas where additional recharge occurs from irrigation practices, water holding in unlined dams, or river flooding events. The flow gradients are steeper to the east where the topographic gradient is also steeper. The flow gradient is minimal on the low lying land near the coast. This condition is probably influenced to some extent by the presence of the salt lakes adjacent to the southwest of the site, which are held at a level above that of the surrounding groundwater.



5.2.3 Recharge Processes

The primary source of recharge to the watertable aquifer in the study area is infiltration of rainfall during periods when rainfall is in excess of evapotranspiration in the winter period. This concept is supported by historical water level gauging data from nearby existing wells which show seasonal fluctuations in groundwater levels consistent with an aquifer that is fed by diffuse rainfall recharge. In a temperate to semi arid climate, like that of Buckland Park, groundwater recharge is typically in the order of 2 – 5 % of annual rainfall. With an average annual total of 442 mm, the estimated annual recharge could be expected to be around 9 – 22 mm/yr. Although the amount of actual recharge would also be affected by soil type, with more clayey soils slowing the infiltration rate of water and reducing the amount of effective recharge. This may well be the case at Buckland Park, where clay occurs extensively in the soil profile.

Additional recharge could be derived from high flows and overbank flooding of the Gawler River. Available information on the river flow regime indicates that this occurrence is somewhat irregular, but such events would provide a significant volume of water for recharge to the shallow aquifer.

Recharge derived from infiltration of excess irrigation waters or leakage from unlined irrigation water holding dams could also occur in localised areas. The extent or significance of this source is not clear, but some areas of local groundwater mounding are evident in the groundwater level data collected from the site.

Where the shallow groundwater flow system is laterally extensive, groundwater inflows can occur from up-gradient and off site. Given that lateral groundwater flow is predicted to occur from northeast to southwest there is likely to be zones of lateral inflow within the aquifer along the eastern and northern boundaries of the site.

5.2.4 Discharge Processes

Groundwater discharge from the watertable aquifer can occur by mechanisms including evaporation directly from the watertable, transpiration by plants, lateral outflow along the flow gradient, baseflow to rivers and drains and extraction by pumping.

Evaporation of groundwater occurs where the capillary fringe zone¹ of the watertable intersects the ground surface. The height of the capillary fringe zone, also known as the evaporation extinction depth, above the watertable varies with soil type, with clayey soils having a higher extinction depth than sandy soils. For this modelling exercise a uniform evaporation extinction depth of 2.3 m has been adopted across the study area. The climate of the study area is one in which potential evaporation exceeds rainfall for most of the year and the average annual potential pan evaporation of 1860 mm exceeds the average annual rainfall by more than four times. Given that a considerable portion of the site is at low elevations and

¹ The capillary fringe is the zone immediately above the watertable into which water may be drawn upward as a consequence of surface tension forces between the water and the soil particles, known as 'capillary action'. When the capillary zone intersects the soil surface water can move to the soil surface via the effects of surface evaporation and dissolved salts, which are not removed by evaporation, may become concentrated at the soil surface.



groundwater levels are very shallow, there is likely to be significant discharge as a consequence of evaporation.

Transpiration of shallow groundwater by vegetation is an important mechanism of groundwater discharge, particularly where deep rooted plants such as native vegetation, orchards or lucerne are present. Recent aerial photography of the site combined with on-site observations indicates that:

- Olive groves are situated adjacent to the northern section of the western boundary of the site;
- Old growth gum trees are scattered across the northern portion of the site, with highest density along the Gawler River; and
- Irrigated agriculture (market gardening) is present in the central portion of the site and along the eastern boundary.

The concepts of evaporation and transpiration are often simplified and considered together as evapotranspiration. A single value is assigned to represent the effective rate of discharge due to these two mechanisms. Evapotranspiration was set at 500 mm/yr for this modelling exercise.

Where the shallow groundwater flow system is laterally extensive, groundwater outflows can occur down gradient and off site. Given that lateral groundwater flow is predicted to occur from northeast to southwest there is likely to be zones of lateral outflow within the aquifer along the western and southern boundaries of the site.

Baseflow of groundwater into the Gawler River, Thompson Creek and the various drainage channels on and around the site is likely to be an appreciable component of groundwater discharge from the site during times when the watertable is elevated above the bed elevations of these features. Field observations made by REM staff indicate that this condition occurs variably across the site and is most common in the low lying areas where groundwater is naturally very shallow.

Extraction by pumping is assumed to be a negligible component of groundwater discharge because the watertable aquifer typically does not provide sufficient water volume or quality to warrant such usage.

5.2.5 River-Aquifer Interaction

The Gawler River is the main hydrological feature affecting groundwater conditions in the study area. The river is ephemeral and only flows following large sustained rainfall events through winter. During these times the river would act as a 'losing stream' meaning that water from the river would recharge into the shallow aquifers, the water levels of which are typically below the river bed. It is possible that there could be a period following sustained wet winter conditions that the river could become a 'gaining stream' for a short period as groundwater discharges from elevated levels in the shallow aquifer in the process of restoring the usual equilibrium.

5.2.6 Influence of Salt Lakes and Drains

The two salt lakes located to the southwest of the site are managed features and are operated with pool levels above that of the surrounding groundwater levels. It is understood that the northern of the two lakes



is held at a level of about 2.85 m AHD and the southern lake is held at about 3.25 m AHD. A network of surface drains surrounding the lakes is intended to provide some management of the ingress of this high salinity water onto the surrounding land. Field observations by REM staff indicate that these drains are probably effective in intercepting some of the discharge caused by mounding beneath the salt lakes, but the flow gradient in the drains is so low that it is unlikely that much of this water moves away from the area. Sampling of monitoring wells installed on the site adjacent to the salt lakes showed that groundwater is hyper saline in that area, and indicates that significant evaporative concentration of salt in the water is occurring in the area. That is water is being discharged by evaporation but salt is left behind causing an increase in the concentration in the remaining water.

Field observations also indicate that the Thompson Creek bed has been deepened and enlarged in places to act as more of a groundwater drain for the surrounding low lying land. This was observed on the south sector west and south sector of the site.

5.3 Numerical Model Development

The MODFLOW software package developed by the United States Geological Survey (MacDonald and Harbough, 1988) was used to simulate steady state, saturated groundwater flow conditions, and Visual MODFLOW software (Waterloo Hydrogeologic Inc., 2001) was used to pre- and post-process the MODFLOW data files.

MODFLOW is a finite difference code that is generally accepted as the industry standard for groundwater flow modelling, and it has a number of sub-routines that enhance its applicability to situations where drainage and groundwater - surface water interactions are important.

Model set up figures detailing the model grid configuration and profile, boundary conditions, recharge zones, evapotranspiration zones and hydraulic conductivity values and model calibration are contained in Appendix H.

5.3.1 Geometry

The model covers an area of approximately 12 km wide and 15 km long that is centred on the area proposed for development at Buckland Park. The model is oriented in a northeast – southwest alignment to match the regional groundwater flow path towards the coast.

The nominal grid dimensions across the model domain are approximately 290 x 280 m. Grid cells have been refined down to approximately 29 x 28 m square within the site area proposed for development at Buckland Park.

The shape of the land surface was interpolated onto the model grid from the available elevation contours using the Surfer™ program. The three layered aquifer system, conceptualised for this modelling exercise, was defined firstly by importing the elevation data for the top of the Glanville Formation as the base of Layer 1. This is the marine sedimentation underlying the St Kilda Formation to the southwest of the site. For the remainder of the area, Layer 1 and Layer 2 of the model were defined with a uniform thickness of 5 m, following the shape of the land surface. The base of Layer 3 was defined by subtracting 20 m from the surface elevation data, giving it a nominal thickness of 10 m.



5.3.2 Aquifer Properties

Hydraulic conductivity values were assigned for each dominant soil type based on experience and the results of the aquifer testing conducted on the 11 new wells installed by REM into the shallow aquifer. Variable hydraulic conductivity was captured in three zones based on interpretation of available lithological information representing, in a simplified way, the varying hydraulic properties of clay, silt and sand. Initial conductivity values were increased during the process of achieving a steady state model calibration in order to balance with the expected recharge rate. The three conductivity zones of the model are 0.75, 1 and 3 m/d (See Appendix H Figures H3, H4 and H5).

Although not specifically used in the steady state model, appropriate aquifer storage values were assigned to each of the three zones.

5.3.3 Boundary Conditions

Constant Head boundaries were assigned to all layers at the up gradient and down gradient edges of the model. At the down gradient end a constant head boundary of 0 m AHD was assigned to represent sea level, while at the up gradient edge a constant head boundary of variable elevation was defined by the shape and elevation of the interpreted groundwater level contour. The constant head elevation graded from 14 m AHD in the south to 10 m AHD in the north.

The MODFLOW Rivers Package boundary condition was used to represent the salt lakes to the southwest of the site. Bed elevation was defined at 2 m AHD from interpretation of available ground surface elevation data and a pool level of 0.5 m above the lake bed was assigned. These details differ somewhat from the information that was provided by the salt lake operator Cheetham Salt, but in the context of this modelling exercise it was necessary to have the levels fit in with the rest of the model data. Bed conductance for the salt lake was set at the low value of 0.001 to represent a low permeability clay liner for the lakes.

The MODFLOW Drains Package boundary condition was used to simulate the Gawler River, Thompson Creek and the drains surrounding the salt lakes. Bed elevations were defined from interpretation of the ground surface elevation data using linear gradients between the known end points. Bed conductance for the drain features was set at 1 to represent a permeable bed that can easily transmit water.

Recharge was applied to the model domain at a uniform rate of 6 mm/yr to simulate rainfall recharge, and evapotranspiration was applied at a maximum rate of 500 mm/yr to simulate the combined effect of evaporation from the groundwater table and transpiration from vegetation. A uniform extinction depth of 2.3 m below ground level was used. These rates are consistent with the average annual rainfall and pan evaporation data published by the Bureau of Meteorology.

5.3.4 Model Assumptions

The following key assumptions have been made in undertaking this steady state modelling exercise:

- The watertable aquifer system occurs in the upper 20 m of the sediment profile and is effectively isolated from the deeper aquifers by an extensive clay aquitard;
- The water level at the up-gradient boundary of the model domain is constant;



- The formations in the modelled profile provide a continuous flow path for groundwater across the model domain, although formation permeability and hence the rate of flow does vary;
- Simplification of variability in the soil profile into the three modelled layers provides reasonable average of soil permeability and effectively represents the hydraulic groundwater flow.
- The Gawler River and Thompson Creek act primarily as groundwater drains;

5.3.5 Model Calibration

The groundwater flow model calibration was undertaken by making reasonable iterative adjustments to model parameters to achieve a close match between predicted and observed groundwater levels. The steady state model was calibrated to a data set of 48 water level measurements from individual wells on and around the site. The data comprised a primary set of wells, including the new wells installed by REM and a selection of existing wells that were gauged on 7 February 2008, combined with a secondary set of wells that had been gauged in March 2007 to provide a broader coverage of data for interpretation. These points were imported into the model as observation wells and modelled results were compared to this data as predicted versus observed values. A model calibration error (mean relative error) of 6.8 % was achieved (See Appendix H Figure H9).

5.4 Model Results

5.4.1 Predictive Scenarios

5.4.1.1 Scenario Overview

Four predictive scenarios were developed to model the future impact of the Buckland Park proposal. These scenarios take into account the steady-state nature of the model. Modelling time varying inputs is beyond the capacity of the model and a separate spreadsheet model was developed to account for the build-up of groundwater beneath stormwater retention ponds. Results from the numerical modelling are reported as the difference in groundwater head between scenarios.

A number of assumptions are made in order to model the hydrological features at the site.

- The new drainage network for the proposal can be represented using the MODFLOW Drains package. This is consistent with the development of the calibration model. With the relatively dry climate at the site, periods of flooding are likely to be infrequent and short. The impact of flood events on groundwater levels is likely to be temporary.
- Recharge beneath the developed area will be reduced due to the presence of paved areas. These paved areas will form a patchwork across the site and in order to simulate this a reduction in recharge is applied across the whole site in order to average out the effect. A visual estimate of the proposal masterplan indicates that approximately 50% of the land surface under development will be paved. This is assumed to have the effect of reducing recharge in this zone by 50%.
- Evapotranspiration beneath the development will be reduced due to the presence of paved areas. The paved areas will form a patchwork of zones with no evapotranspiration across the site and a uniform reduction in the maximum evapotranspiration rate has been applied to



account for this. However, residential gardens are likely to comprise more deep-rooting vegetation. This will lead to an increase in evapotranspiration on the vegetated areas. The assumed net effect of the development on evapotranspiration is an overall reduction of the maximum evapotranspiration rate of 30%. A complicating issue is that although the maximum evapotranspiration rate has been reduced this only applies where the depth to water table is less than the extinction depth.

- Stormwater retention will occur in a detention basin at the downstream end of the new drainage network. This is predicted to contain water at a depth of approximately 1m for several days after rainfall events and the detention time will vary depending on weather conditions. The steady-state model is not capable of modelling these fluctuating conditions and the impact of the detention pond will be modelled separately using a spreadsheet model.
- The predicted 0.3 m rise in sea level is modelled by raising the groundwater level in the constant head boundaries representing the current coastline. Data relating to the predicted average sea level coastline from geomorphic modelling was not available and it is assumed that the numerical groundwater model will respond in a realistic manner as a result of raising the constant head boundaries.

5.4.1.2 Baseline Scenario: No Development, Current Climate

The baseline scenario models the conditions prior to development and provides the basis with which to compare the other scenarios. This is represented by the model as calibrated and has the following boundary conditions:

- 6 mm/yr of uniform recharge across the model;
- Gawler River, Thompson Creek and existing groundwater drains represented using the MODFLOW Drains package;
- The Cheetham Salt Pans represented using the MODFLOW Rivers package with a constant pool of surface water of 0.5 m and a low permeability bed;
- Sea level set at 0 m AHD elevation and modelled at the coastline's present location based on interpretation of aerial photographs; and
- Upgradient (regional) groundwater levels controlled by constant head boundaries.

5.4.1.3 Scenario A: No Development with Climate Change

In order to assess the relative impact of the individual components it is necessary to determine the incremental difference to groundwater levels as a result of a sea level rise due to a change in climate. On the basis of the International Panel on Climate Change projections, the Coast Protection Board recommends a mid-range sea level rise of 0.3 m by the year 2050 be adopted for coastal planning and design (Coast Protection Board 2004). It is noted that, while the effects of a sea level rise have been modelled, the Buckland Park site lies outside the jurisdiction of the Coast Development Board and regulatory controls do not apply to the development.

Scenario A maintains the same boundary conditions as the baseline scenario with the addition of:



- Constant Head Cells at the current coastline set at 0.3 m AHD.

5.4.1.4 Scenario B: Development with Current Climate

The Buckland Park proposal will introduce a set of new conditions at the site. These will include the construction of roads and housing and the installation of drainage and stormwater detention ponds. These have been represented in the model by:

- Reducing recharge beneath the development footprint by 50% to 3 mm/yr;
- Reducing maximum evapotranspiration beneath the development footprint by 30%;
- The new drainage network modelled using the MODFLOW Drains package; and
- Stormwater retention modelled separately using a spreadsheet model to determine radial extent of impact.

5.4.1.5 Scenario C: Development with Climate Change

The total impact on site of the Buckland Park development and the results of a sea level rise due to climate change (in 2050) are modelled in scenario D. This is achieved by combining the boundary condition changes for scenario B and scenario C. These include:

- Reducing recharge beneath the development footprint by 50% (3 mm/yr);
- Reducing maximum evapotranspiration beneath the development footprint by 30%;
- The new drainage network modelled using the MODFLOW Drains package;
- Stormwater retention modelled separately using a spreadsheet model to determine radial extent of impact; and
- Constant Head Cells at the current coastline set at 0.3 m AHD.

5.4.2 Modelled Groundwater Levels

5.4.2.1 Baseline Scenario

The results of the baseline scenario (the calibration model) are presented in Figure 5.4. The modelled contours grade from east to west across the model and are in reasonable agreement with measured groundwater levels (Figure 5.5)

5.4.2.2 Scenario A: No Development with Climate Change

The groundwater response to this scenario is shown in Figure 5.6. This figure represents the difference between the baseline scenario and scenario A as a result of no change in recharge or evapotranspiration and a 0.3 m rise in sea level.

The results indicate that impacts to groundwater from sea level rise associated with climate change are limited to the coastal zone. Raised groundwater levels are largely restricted to the zone west of the salt lakes which, given the projected rise in sea level, is likely to be either inundated or within the littoral zone. Outside of this area there are minor rises in groundwater beneath the salt lakes.



5.4.2.3 Scenario B: Development with Current Climate

The groundwater response to scenario B is shown in Figure 5.7. This figure represents the difference between the baseline scenario and scenario B resulting from a 50% reduction in recharge and a 30% reduction in evapotranspiration beneath the development footprint and no change in sea level.

The impacts on groundwater levels arising from the development are largely contained to within the Buckland Park site boundary. There is minimal impact on areas outside of the development. Groundwater levels beneath the development footprint are either reduced (increasing the depth to water table) or neutral in comparison to the baseline scenario. The area displaying the greatest falls is located in the north sector of the site south of the Gawler River.

5.4.2.4 Scenario C: Development with Climate Change

The groundwater response to scenario C is shown in Figure 5.8. This figure represents the difference between the baseline scenario and scenario C resulting from a 50% reduction in recharge and a 30% reduction in evapotranspiration beneath the development footprint and a 0.3 m rise in sea level.

The impacts on groundwater levels under this scenario are two-fold and occur in spatially discrete zones of the model. The impacts of sea level rise as a result of climate change are again restricted to the zone west of the salt lakes with some raised groundwater levels beneath the salt lakes. There is a clear spatial separation between the impacts of sea level rise and the impacts occurring from the development. The developmental impacts on groundwater level result in a decline in groundwater levels beneath the development site. The greatest decline in groundwater levels is observed in the northern sector of the site south of the Gawler River.

5.4.2.5 Discussion of Numerical Modelling Results

The results from each of the scenarios indicate that there are limited impacts arising from either the development or sea level rise associated with climate change. In particular the effects of a 0.3 m sea level rise do not impact on the proposal site and are largely restricted to the coastal zone and salt lakes. A further 0.7 m rise in sea level to 1 m AHD is likely to result in increased groundwater levels moving further inland but probably no further than the salt pans. This additional hydraulic buffer may result in a decrease in the zone of groundwater level depression beneath the development site.

The model estimates that the model creates a decline in groundwater levels centred largely on an area south of the Gawler River. The decline in groundwater levels is attributed to the assumption of a decrease in recharge beneath the development site as a result of paved areas. Where paving exists surface water cannot recharge the groundwater and hence the overall volume of recharge is reduced. Reducing recharge leads to a minor fall in groundwater levels. This is partly offset by the decrease in evapotranspiration that occurs when an area is paved. This modelling is conducted on the assumption that parks and suburban gardens will, to some extent, create additional evapotranspirational losses due to the different water use between the current vegetation (largely grassland) and suburban vegetation (with an increased number of deep rooted trees and other species). The net effect of this is an assumed 30% reduction in the maximum evapotranspiration rate. If suburban gardens are over-watered there is the potential for recharge from suburban gardens to increase and this may change the results. However, current water restrictions are likely to continue into the future and excess recharge due to overwatering is not viewed as a problem.



The occurrence of the groundwater declines in close proximity to the Gawler River may result in decreased flows within the river as there is an increase in the potential for the stream to lose water due to the increased difference in head between the river and the groundwater. The degree of change beneath the development is minor and therefore, while the potential exists for reduced winter flows in the Gawler River, it is unlikely that the groundwater level decline will impact significantly. Surface water/groundwater interactions have not been explicitly modelled within this study.

5.4.3 Modelled Stormwater Retention

Stormwater retention was specifically excluded from the numerical modelling. This was due to the fact that stormwater basin filling and emptying cycles depend on the variable nature of rainfall and runoff within the natural system. This variability cannot be effectively modelled within the steady-state model. Instead the impact of stormwater retention within the detention basin is modelled using a spreadsheet model. This is based on the Hantush formula for determining the groundwater level in a bore from the well-function.

A number of assumptions are made:

- The formula assumes a point source of recharge; and
- A circular pond of a set radius.

A summary of stormwater retention scenarios is presented in Table 5.1.

5.4.3.1 Stormwater Retention Scenarios

The details of operation of stormwater retention at the Buckland Park site have not been determined as yet. Rainfall/runoff modelling has not been conducted nor an operation plan formed as the engineering works are in the design phase. A range of scenarios were examined to model the impact of retaining water within the detention pond. These largely relate to the use of a pond liner to prevent leakage from the base of the pond and to the residence time of water within the pond.

- **Ornamental Pond**

The design of the stormwater system is to collect and dispose of surface water runoff. The Buckland Park design plans indicate a series of ponds and wetlands. This scenario is designed to account for the presence of an ornamental pond rather than a disposal basin. Water is maintained in the pond to a depth of 1m all year and options are examined for a lined or unlined pond which affects the amount of recharge to the water table through the base of the pond.

- **Winter Retention**

This scenario is designed to model the situation if there are significant rainfall events over winter. Surface water will be maintained in the detention pond and may be periodically refilled by further rainfall events lengthening the retention time of water in the pond. The three months of winter (90 days) are modelled with options for a lined or unlined pond which affects the amount of recharge to the water table through the base of the pond.



- **Month Long Retention**

An intermediate scenario is modelled that represents increased rainfall that occurs sporadically throughout winter leading to a retention time in the basin of one month (30 days) with options for a lined or unlined pond which affects the amount of recharge to the water table through the base of the pond.

- **Single Event**

The designed detention time for a single event is 10 days. This has been modelled with both a lined and unlined pond which affects the amount of recharge to the water table through the base of the pond.

5.4.3.2 Stormwater Retention Modelling Parameters

Parameters used in the modelling of stormwater retention are shown in Table 5.1. The design plans indicate that there are up to three ponds grouped together. The model assumes a circular pond with a point source of recharge located at the centre.

- The area of the ponds provided is 15 ha, which equates to a pond radius of 218m;
- The model is 20 m thick;
- Observed groundwater levels adjacent to the proposed detention ponds indicate a depth to groundwater of 2.2 m;
- An hydraulic conductivity value of 3 m/day is used as indicated in the numerical model; and
- An assumed specific yield of 0.01 is consistent with the geology.

5.4.3.3 Detention Pond Recharge Estimation

One of the critical inputs into the model is the estimate of recharge for leakage from the detention pond to the watertable. Leaky lined dams are estimated as having more than 2 mm/day of leakage through the dam walls (Coles 2003). A conservative estimate of pond leakage is applied here for the lined scenarios of 0.5 mm/day. For unlined ponds the rate of leakage or recharge is less well constrained and depends on the properties of the soil from which they have been constructed. It is assumed here that the detention pond will be constructed from soils derived from the top 5 m of the geological profile and therefore have an equivalent hydraulic conductivity to the top layer of the model (3 m/day). Darcy's Law was applied to determine the flux across the base of the pond and assumed:

- $k=3$ m/day
- $i=0.005$
- $A=150\,000$ m²

Darcy's Law gives: $Q = kiA = 2250$ m³/day
 $= 821250$ m³/yr

This is equivalent to a recharge rate of :



$$\begin{aligned} Rr &= Q/A = 821\,250/150\,000 \\ &= 5.475 \text{ m/yr} \\ &= 0.015 \text{ m/d} \end{aligned}$$

This value has been used to simulate the recharge through the base of an unlined detention pond.

5.4.3.4 Stormwater Retention Modelling Results

The results of the spreadsheet modelling of stormwater retention are presented in Figures 5.9 and 5.10 and Table 5.2.

Results indicate that for a lined pond there is little impact on groundwater levels in the surrounding aquifer but for an unlined pond there is significant groundwater mound build-up beneath the pond.

For a lined pond the highest degree of mound development beneath the pond is 0.62 m (Figure 5.10) for a permanent ornamental pond. The majority of this impact (>0.2 m) occurs within 1000 m of the centre of the pond.

For an unlined pond even at the shortest detention time there is mound build-up beneath the pond. The unsaturated thickness of the aquifer in this region is 2.2 m and mound build-up is in excess of this under all scenarios. The spreadsheet model does not account for groundwater levels breaching the surface and returning to the surface water system, as such the spreadsheet model predicts unrealistically elevated mound build-up levels that must be interpreted as the watertable rising to ground level. Once the watertable has risen to above the base of the pond, the pond would cease to lose water to the groundwater system and would collect groundwater. The spreadsheet model also assumes a continuous supply of water to feed the recharge rate. Therefore it is concluded that even at the lowest retention time designed for the pond, it will become a gaining system.

The radius of impact for the different scenarios increases with detention time. If a 1m rise in groundwater level is considered a significant impact then for an unlined pond the radius of *significant* impact (>1m rise) occurs at approximately:

- 450m (10 days);
- 750m (30 days);
- 1600m (90 days); and
- 3000m (365 days).

It must be stressed that these calculations provide indicative estimates of impacts only. The results will be highly sensitive to assumptions regarding aquifer properties such as the specific yield, which can vary over short distances. The results indicate that further investigation of the impacts may be required once the detail design of the ponds has been undertaken.

The potential impact of unlined ponds is likely to be over-estimated given that a skin of silty material will most likely exist at the base of the pond which will act as a barrier to leakage. Leakage will also be buffered by evaporation which will reduce the rate of mound buildup.



5.4.4 Stormwater Detention Impacts on Groundwater Salinity

The stormwater retention modelling demonstrates that in an unlined detention pond there would be build-up of groundwater beneath and surrounding the pond. This will form a fresh water lens that sits on top of the regional saline groundwater. A degree of mixing will occur at the edges of the mound. It is inferred from the modelling that wherever surface water pools in the landscape (such as in the channels or detention ponds) and groundwater levels lie below the base of the channel/pond there is the potential for the channel/pond to lose water to the groundwater system and for a mound to develop. This mound will have the effect of diluting salinity in areas around these drainage features. This is minimised where a lining is used on the channel or pond.

5.5 Conclusions

The results from the numerical model demonstrate that there will be negligible impacts from sea level rise due to climate change and that impacts arising from sea level rise will occur off-site. The impacts from the development will be to reduce groundwater levels beneath the development site by a minor amount due to a decrease in recharge and evapotranspiration losses. A reduction in groundwater levels of 0.2m or less can be considered to be insignificant and unlikely to be discernable from climate driven groundwater level fluctuations.

In terms of stormwater retention at the downstream end of the drainage system, where shallow watertables are encountered, it is probable that if the detention pond is unlined it will recharge the groundwater system until groundwater levels rise to a level equal with the surface water levels. If surface water levels are subsequently lowered, groundwater will then drain back into the detention ponds. An unlined pond results in rises in groundwater in the region surrounding the pond and would have an increased level of risk associated with it. The spreadsheet modelling indicates that a lined pond would have a lower level of risk associated with it raising groundwater levels by a minor amount in a localised area.

It must be stressed that these calculations provide indicative estimates of impacts only. The results will be highly sensitive to assumptions regarding aquifer properties such as the specific yield, which can vary over short distances. The results indicate that further investigation of the impacts may be required once the detail design of the ponds has been undertaken. Additional data will be needed to determine aquifer properties near the proposed ponds.



6 Potential Impacts of Development

6.1 Engineering Impacts

There are a range of engineering issues relating to impacts of specific activities on the groundwater conditions at the site during development operations. A discussion of these is provided in this section.

Without specific operational information it is difficult to assess in detail the likely impact on groundwater during operations. However it is possible to make some general statements relating to the impacts from works on the site.

6.1.1 Groundwater Protection Measures During Operations

Groundwater flow is from northeast to southwest across the study site. Changes to this groundwater flow regime may impact on the coastal environments and Gawler River. The likely cause of disruption to groundwater flow is considered to be from groundwater extraction for the purposes of deep trenching operations. This would entail extraction of groundwater in the trenching zone, lowering the watertable to enable trenching to occur coupled with water retention ponds. The impact of a falling watertable in the study area will greatly depend on the location of the fall.

Retention of groundwater in ponds is a likely adjunct to groundwater extraction as the groundwater extracted is likely to be of high salinity and hence inappropriate for discharge to either the Gawler River or the coast under the Natural Resources Management Act 2004. This will require construction of retention ponds. There will be a degree of seepage through the base of the ponds that is dependent on their construction. Contingent on the location of the ponds high salinity seepage to the watertable may occur through build-up of a groundwater mound beneath the pond over the longer term and the development of a groundwater gradient from this mound causing groundwater flow and discharge to the river or coast. The resulting high salinity discharge to a receiving environment may impact negatively on these environments. Impacts of this type may be diminished by the use of pond linings and careful selection of pond sites in relation to the riverine and coastal environments.

6.1.2 Effects of Waterway Construction

The construction of wetlands and parks is a high-profile part of the Buckland Park development. This will involve the construction of waterways and retention ponds which will have an impact on groundwater. A new drainage system is proposed in order to mitigate flooding problems associated with extreme flows down the Gawler River. The worst case flood scenario is predicted to flow along Thompson Creek south of Park Road (Connell Wagner 2007). Floodways are proposed to be constructed in this area and also along the western boundary of the Buckland Park Site.

Issues relating to these locations are similar to the construction of temporary retention ponds. However rather than highly saline seepage these areas are likely to experience low salinity seepage as per the stormwater retention spreadsheet monitoring. Any form of seepage will result in the development of a groundwater mound beneath permanent bodies of water. However, in the case of low salinity water this may be seen as beneficial. Due to density differences low salinity water will float on top of high salinity water and form a groundwater lens. This fresh water lens may provide sufficient underground fresh water to support ecosystems that would not survive under the current high salinity groundwater regime. In effect



the ponds and wetlands may create a fresh water buffer surrounding them that supports trees and shrubs. Alongside this effect will be a concurrent rise in the water table in these areas. This will have the effect of forcing water away from the groundwater mound developed beneath the wetlands where it will appear as high salinity discharge to these water bodies. In addition the presence of the wetlands will contribute to rising water tables. In this area, with a shallow water table, any rise is considered likely to exacerbate already occurring dryland salinity problems as the water table enters the evapotranspiration zone and salts become concentrated in the soil profile near the land surface.

6.1.3 Engineering Requirements for Infrastructure

Detailed design of engineering infrastructure is outside the scope of this initial stage of works. Without further information regarding the location of proposed development and infrastructure it is not possible to develop specific requirements for engineering solutions. However, it is possible to comment on some options available.

Small scale salt groundwater lowering schemes can be used to mitigate groundwater mounding. These schemes could involve using spear points to collect water and distributes the collected high salinity water to a disposal basin. A similar scheme might potentially be used along proposed waterways. This may not be required if deep rooted perennial vegetation can be established in the fresh water lens developed along the waterways to mitigate the impact of lateral movement of saline groundwater on vegetation health.

Groundwater drainage is another option to be considered. The installation of a drainage network through the area would prevent the watertable from rising above the level of the drains. This would require the development of a disposal basin for drainage.

A further method to be considered would be to construct a groundwater disposal scheme to actively induce a cone of depression beneath the site lowering water tables regionally and adjusting the groundwater flow regime. Such a system would be susceptible to seawater intrusion and baseflow losses from the Gawler River.

In all cases there is a need to dispose of high salinity water to a disposal basin. The location of a retention pond to concentrate high salinity water in the vicinity of the engineering works would be required.

Although there is the potential to negotiate the use of Cheetham Salt evaporation ponds as a disposal site it is considered unlikely that an active groundwater disposal scheme will be required. If a groundwater disposal scheme were to be developed this would require a separate application and environmental management plan to be developed.

6.2 Salinity Impacts

6.2.1 Introduction

The modelling undertaken to assess changes to shallow groundwater levels assumes that recharge across the whole of the development footprint will reduce due to the presence of large paved areas and higher water use from gardens and parks.



However there is a potential for other impacts to occur if poor irrigation practices in residential and recreational areas were poor. Under this scenario excess irrigation water would percolate to the watertable causing a rise in levels or percolate downward to low permeability clay and form a perched layer of water. In either of these cases there is a risk of waterlogging and/or salinity problems.

This part of the analysis identifies where salinity impacts may occur under this scenario.

Salinity occurring in an urban environment is commonly referred to as ‘urban salinity’ and occurs throughout Australia in areas where dryland or irrigation induced salinity is prevalent. Potential impacts from urban salinity include:

- Declining tree health and tree death;
- Loss of vegetation and replacement with more salt tolerant species eg. sea barley grass, samphire plants, salt bush etc.
- Poor plant growth including the development of bare patches in lawn areas, including playing fields;
- Rising damp in houses and deterioration in concrete paths and paved areas;
- Fretting of bricks and mortar and a deterioration in house foundations; and
- Corrosion of underground services and deterioration of road infrastructure;

6.2.2 Urban Salinity Risk Classification

In the context of residential development, the relative risk of urban salinity is provided by the combination of groundwater depth in the regional watertable aquifer and the occurrence of subsurface clay in the upper 4 m of the soil profile. The approach adopted here categorised five levels of urban salinity risk on a scale grading from low to very high and the level of management response varies accordingly. The logic behind the five risk levels is summarised as:

Low: Groundwater is below the threshold level of 4 m bgl and a clay layer does not occur shallower than the 4 m bgl threshold for perched groundwater potential. The resulting risk of urban salinisation is low and this would be the land most suitable for development from an urban salinity perspective.

Moderate: Groundwater is below the threshold level of 4 m bgl and a clay layer is present in the upper 4 m of the soil profile. While regional groundwater is not a concern in these areas, there is potential for perched groundwater to develop on top of the clay layer, which presents a considerable hazard to urban development. These areas have been assigned a moderate risk level because the hazard is relatively easy to manage with the installation of a suitable drainage system. Shallow regional groundwater on the other hand is much more difficult to manage and is therefore assigned a high or very high level of risk.

High(a): Groundwater is 2 - 4 m bgl and the clay does not occur shallower than the 4 m bgl threshold for perched groundwater potential. In these areas groundwater is within the zone of concern for urban development and although not currently causing salinisation, poor water management could rapidly cause the onset of saline conditions.



High(b): Groundwater is 2 - 4 m bgl and there is potential for perched groundwater to develop on top of a clay layer in the upper 4 m of the soil profile. In addition to the hazard of perched groundwater, regional groundwater is within the zone of concern for urban development and although not currently causing salinisation, poor water management could rapidly cause the onset of saline conditions.

Very High: Groundwater is less than 2 m bgl. In these areas shallow saline groundwater is an immediate threat to urban development and some land may have already become salinised. The presence of salt tolerant plant species would automatically classify the affected land with a very high level of risk. Any development in such areas must be subject to the most rigorous management approach which acknowledges the liabilities.

6.2.3 Urban Salinity Risk at Buckland Park

The application of this urban salinity risk classification system to the Buckland Park site is presented spatially in Figure 6.1, showing the interpreted distribution of risk classes across the site. This interpretation was produced from the depth to groundwater information for the 2 July 2008 gauging event overlain with the depth to clay information derived from the lithological data obtained from new and existing drill holes.

The interpreted salinity risk across the Buckland Park site is essentially defined by the depth to groundwater information. That is, risk levels are lowest along the Gawler River where the watertable is deepest and risk levels are highest on the low lying portions of the site, particularly in the south and west. The extensive presence of clay material in the upper 4 m of the soil profile increases the salinity risk across the site due to the potential for perched watertables to develop. This is particularly pertinent to areas where clay is in the subsurface and is overlain by a more permeable material such as sand or silt that could act as an aquifer.

Where clay is at or very near the ground surface, as delineated in Figure 4.1, the potential for perched groundwater to develop and pose a threat might not be as significant because there is not enough overlying material to hold any perched groundwater. The output of the salinity risk assessment should be considered with this in mind.

6.2.4 Management of Urban Salinity Risk

While most of the area proposed for development was assessed to be at moderate or higher risk of urban salinity, it is likely that development could still proceed in most areas, providing that adequate salinity management measures are adopted. An overview of selected urban salinity risk management options is provided in Appendix I.

In all cases the promotion of good water management practices such as efficient lawn and garden watering and appropriate disposal of stormwater and grey water should be encouraged. This would include stormwater management systems that ensure ponding and subsequent groundwater recharge do not occur in areas susceptible to perched or shallow groundwater. In the higher risk areas and particularly where shallow regional groundwater is a threat, efficient water use should be a key feature of the development.

If development is to proceed in very high risk areas, where shallow regional groundwater is a threat, detailed assessments and implementation of appropriate management and engineering solutions will be



required. Where there is potential for perched groundwater to develop the installation of a subsurface drainage system is may be a requirement of urban development.

Management strategies must be concerned with maintaining groundwater at a safe depth below ground level and efficient water use practices to minimise groundwater recharge. For example, imported clean fill may be used to elevate the ground surface above the groundwater capillary fringe zone. However, the potential for disruption to groundwater flow up gradient of the development must be thoroughly investigated and addressed with suitable drainage prior to implementation.

6.3 Climate Change

6.3.1 Climate Predictions

Recent research work by DWLBC (Bardsley 2006) on climate change suggest that there has been a warming trend for the Adelaide region throughout the latter part of the Twentieth Century, and projected climate change studies suggest that this trend is likely to continue. The trend regarding rainfall volume, intensity and pattern for the region is far less clear, although projections suggest a drying trend in the future.

Climate change predictions of increased evaporation and altered temporal rainfall are likely to result in a reduction in baseflow to creeks and streams across the Adelaide region which has significant implications for wetland habitats and groundwater recharge.

In addition coastal management will need to respond to the impacts of climate change with a rise in sea level of between 0.09-0.88 m (Bardsley 2006). The Coast Protection Board of SA (1992) uses a projected rise of 1 m by 2100 to inform planning considerations to account for the impact of rare events associated with high tides, local flooding, wave action and storm surges. The Board is recommending that a mid-range sea level rise of 0.3m by the year 2050 be adopted for most coastal planning and design

While acknowledging that there remains significant uncertainty surrounding the probable consequences of climate change there are likely to be impacts on the Buckland Park site.

6.3.2 Sea Level Rise

The results of the numerical modelling demonstrate that the impacts of sea-level rise on Buckland Park will have some ramifications.

- Sea level rise will push the shoreline and associated processes further inland.
- As the shoreline encroaches, groundwater levels will rise as a result of the increased hydraulic pressure.
- Groundwater salinity is likely to increase along the newly established shoreline and groundwater mixing will result in increased salinity further inland.
- The higher salinity water may create density stratification as perched fresh water is raised hydraulically by underlying saline water.



- The rising watertable may have the capacity to intersect the land surface or enter the evapotranspiration zone resulting in increased dryland salinity and potential waterlogging impacts throughout the Buckland Park site.

The limit of these effects can be predicted by interpreting the change in groundwater level contours in Figure 5.6. The limit of groundwater level rises due to a 0.3 m sea level rise as a result of climate change occurs within the zone currently occupied by the salt lakes. This is outside the area occupied by the Buckland Park development, however, the zone of influence of shoreline processes and the groundwater mixing zone may encroach to the western margin of the Buckland Park site.

Engineered sea defences and drainage solutions may provide a suitable defence against these impacts. Possible techniques that reduce the impact of storm events or limit the impact of coastal inundation include sea walls, levee banks, tidal barriers, pumps and ponds.

While it may not prove necessary to use these features it is recommended that allowance is made for construction of these or similar solutions within the planning phase.



7 Conclusions and Recommendations

7.1 Conclusions

- Subsurface clays occur extensively throughout the study area at depths of less than 4 m bgl. These clays will act as an impediment to downward movement of water and, in the case where they are overlain by more permeable sediments like sand or silt, there is potential for development of shallow perched watertables to develop.
- Groundwater depth across the study area is often less than 4 m depth. In addition, problems associated with water logging and salinity are most likely to occur in areas where the depth to groundwater is less than 2 m bgl.
- The results from the numerical model demonstrate that there will be negligible impacts from sea level rise due to climate change and that impacts arising from sea level rise will occur off-site.
- The impacts from the development will be to reduce groundwater levels beneath the development site by a minor amount due to a decrease in recharge and evapotranspiration losses. A reduction in groundwater levels of 0.2m or less can be considered to be insignificant and unlikely to be discernable from climate driven groundwater level fluctuations.
- Stormwater retention in unlined ponds and channels may cause localised groundwater mounding. The development of a groundwater mound increases the level of risk from rising watertables and waterlogging. Lined ponds and channels would have a far lower level of associated risk, raising groundwater levels by a minor amount in a localised area. It must be stressed that these calculations provide indicative estimates of impacts only. The results will be highly sensitive to assumptions regarding aquifer properties such as the specific yield, which can vary over short distances.
- Interpreted salinity risk associated with poor irrigation practices in the urban environment are lowest along the Gawler River where the water table is deepest and highest in low lying areas to the south and west. Most areas of the proposed development were assessed to be at moderate or higher risk of urban salinity.



7.2 Recommendations

- Engineering works that impact on groundwater during operations and drainage works in the longer term should utilise carefully selected lined retention pond sites, subject to a more detailed assessment of the impacts of stormwater retention.
- Development in areas identified at a moderate or higher urban salinity risk should be subject to specific water management requirements. Some engineering controls may be required where the salinity risk is high.
- Further investigation of the potential impacts of stormwater retention ponds may be required once the detail design of the ponds has been undertaken. Additional data will be needed to determine aquifer properties near the proposed ponds.
- Management strategies must be concerned with maintaining groundwater at a safe depth below ground level and efficient water use practices to minimise groundwater recharge.



8 Statement of Limitations

This report has been prepared in accordance with the program outlined in the proposal prepared for Walker Corporation Pty Ltd dated 13 November 2007. The services performed by REM have been conducted in a manner consistent with the level of quality and skills generally exercised by members of its profession and consulting practice. No warranty or guarantee of site conditions is intended.

This report is solely for the use of Walker Corporation Pty Ltd and may not contain sufficient information for purposes of other parties or for other uses. Any reliance on this report by third parties shall be at such parties' sole risk. This report shall only be presented in full and may not be used to support any other objectives than those set out in the report, except where written approval with comments are provided by REM.

The information in this report is considered to be accurate with respect to information provided and conditions encountered at the site at the time of investigation and considering the inherent limitations associated with extrapolating information from a sample data set. Subsurface conditions can vary across a particular site and no practical degree of sampling can ever eliminate the possibility that conditions may be present at a site that have not been represented through sampling. Actual conditions in areas not sampled may differ from predictions.

REM has used the methodology and sources of information outlined within this report and has made no independent verification of this information beyond the agreed scope of works. REM assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that the information provided to REM was false.

Since subsurface conditions (including contamination concentrations) can change within a limited period of time and space, this inherent limitation to the representation of site conditions provided by this report should always be taken into consideration particularly if the report is used after a delay in time. No responsibility for any changes in site conditions beyond the time of this investigation is assumed by REM.



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Tables

Figures

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Historical time-series water level data from available wells

Appendix B

Drilling Logs for wells installed by REM

Appendix C

Well permits for wells installed by REM

Appendix D

Bore purging and groundwater sampling data sheets

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Aquifer testing analysis sheets

Appendix F

Laboratory analytical reports

Appendix G

Analytical data quality assessment

Appendix H

Model setup figures

Appendix I

Overview of selected urban salinity risk management options

Appendix J

Buckland Park development proposal overview