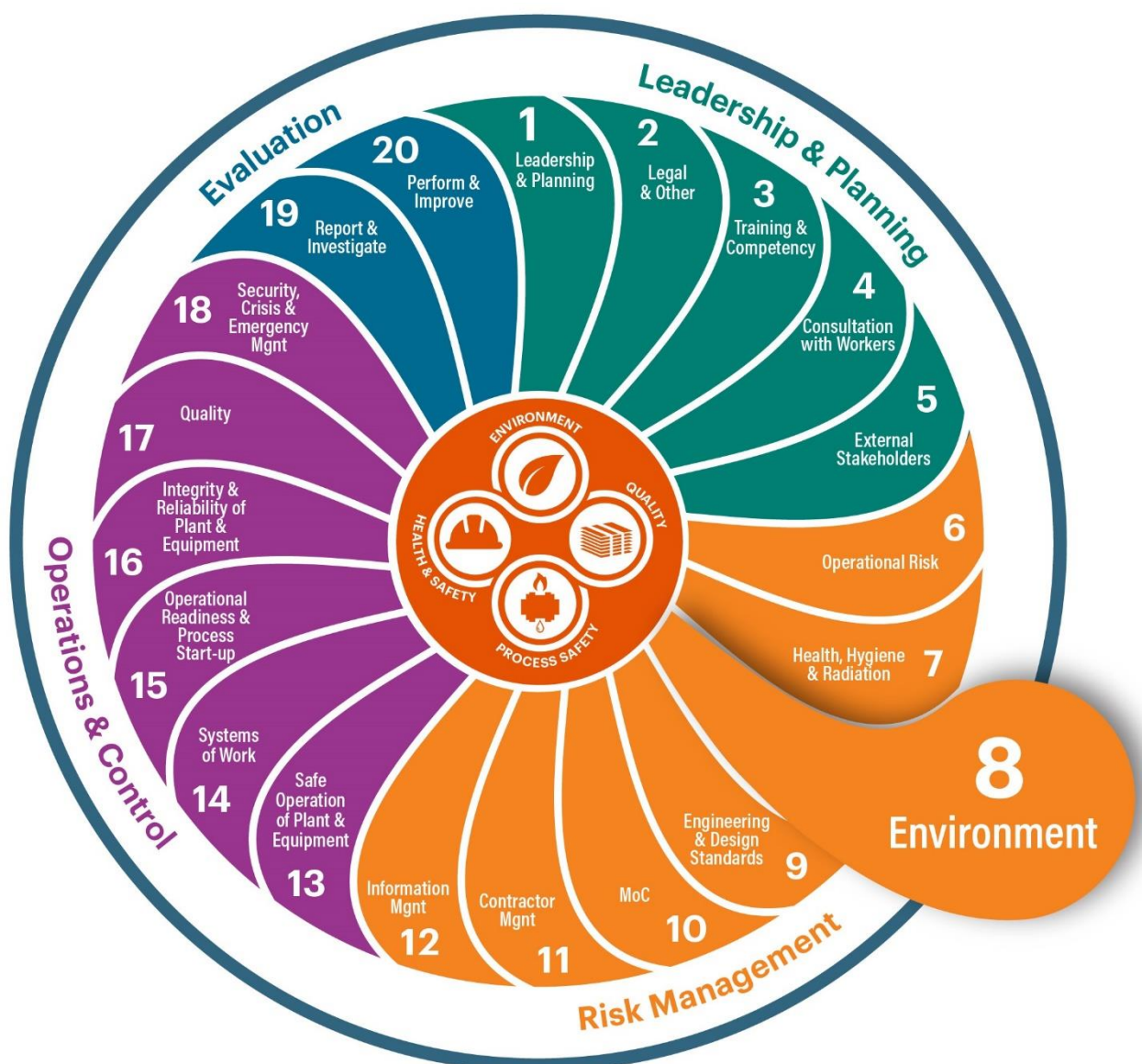


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1 PURPOSE

This document supports *IMS Element 8: Environment Standard, Doc No 012513194*

2 SCOPE

This Monitoring Program (MP) describes the environmental monitoring activities undertaken by BHP Olympic Dam Corporation Pty Ltd (ODC) for the purpose of quantifying any change in the extent or significance of impacts of ODC's operations on the Great Artesian Basin (GAB) water supply, assessing the performance of the control measures employed to limit these impacts, and to meet relevant legal and other requirements.

This MP addresses a number of distinct elements of GAB monitoring. For each element, the MP sets out some background information, the purpose of the monitoring and the deliverables which are produced as a result of the monitoring. This MP also includes a description of the methods for measuring achievement of **compliance criteria** and the movement of trends towards **leading indicators** (where applicable).

The GAB water supply for Olympic Dam, and the associated townships and accommodation villages (including Andamooka), is obtained from wellfields located on the south-western edge of the GAB (see Figure 6-1 and Figure 5.2). The GAB aquifer in South Australia (SA) is confined by shales above and by basement rocks below. As a result, groundwater pressure in the GAB aquifer is sufficient to create artesian conditions, i.e. most wells near the ODC wellfields supply groundwater by free-flow.

Most of the recharge to the GAB aquifer is from distant rainfall, and apart from springs, natural discharge in South Australia is by diffuse upward flow and eventual evaporation. There are numerous GAB springs in the vicinity of the Olympic Dam Wellfields A and B, which support an array of important flora and fauna adapted to these aquatic habitats. GAB springs occur near the margins of the basin where the aquifer is shallow and the shale aquitard is thin, enhanced by structural weaknesses (faults) providing low-conductivity conduits that transmit the pressurised GAB groundwater upwards.

Several pastoral properties, which rely on the GAB for water supply, also operate in the vicinity of the wellfields. These properties rely on artesian pressure to distribute water along extensive piping systems. Management of the GAB is closely aligned with the management of aquifer pressure of the GAB, pastoral bore flow and flow at GAB springs. A discussion of the GAB hydrogeology is included in Appendix B. The history of development of the wellfields is discussed in Appendix C.

The aim of the procedures described in the MP is to measure and assess the **environmental impacts** associated with water abstraction from the wellfields by:

- Delineating the drawdown induced by the wellfields, and particularly any impact on pastoral water supplies and environmental flows;
- Identifying possible changes in water chemistry that may occur;
- Enable assessment of compliance with legal requirements for the operation of the GAB water supply in the annual Wellfield Report;
- Enable assessment to ensure that impacts are within predictions and expectations in the annual Wellfield Report;
- Increase the understanding of the hydrogeological dynamics of the GAB in the wellfields region.

To meet these objectives, data are collected on the hydrogeology of the GAB from an extensive area within the wellfields region. These data are used to measure the extent of drawdown and its influence on the natural chemistry, flows and pressures of pastoral bores and springs.

Management tools are prepared to ensure rapid response to adverse changes in GAB spring and bore flows within the wellfields region.

2.1 Responsible ODC personnel

The Olympic Dam Asset President is responsible for ensuring that all legal and other requirements described in this MP are met.

ODC employs hydrogeologists and sufficient other staff with experience and qualifications to fulfil the requirements of this MP.

2.2 Review and modification

This MP is reviewed annually. Major changes or amendments following the review are documented in the *Environmental Management Program Targets, Actions and Major Changes, Doc No. 000114697*.

It should be noted that as a result of operational activities or through optimisation of sample design some existing monitoring sites may be lost and others added (where possible) to maintain the integrity of the sampling program. Access restrictions can result in some sites occasionally being unable to be monitored.

3 DETAILED PROCEDURE

Management of the impacts on the GAB water supply is closely aligned with the management and assessment of aquifer pressure and water quality at bores and springs within the vicinity of the wellfields. A contingency measures and response plan has been prepared to address any significant adverse or unexpected variations in drawdown or spring flow rates within the wellfields occurring as a result of water extraction (BHP Billiton, 2007). Spring flow, bore pressure and aquifer quality data throughout the wellfields area have been collected by ODC for over 30 years. These data provide baseline information and aid in the understanding of the natural systems to enable assessment of the impacts of ODC water supply operations and compliance with regulatory requirements. Data continue to be collected according to the schedules in section 9.

3.1 Wellfield B drawdown contouring

3.1.1 Background

Water use from Wellfield B is regulated according to regional effects on pressures in the GAB. The main management considerations are preserving flows at GAB springs, maintaining overall sustainability of the water resource, and maintaining pressure at pastoral wells.

The Wellfield B compliance assessment is based on a drawdown footprint, being the area contained within the 10 m drawdown contour, together with criteria relating to sites S1 and S2 to protect GAB springs. This method relies on a 'whole-of-wellfield' approach as opposed to drawdown reported at individual points. A drawdown map, based on observations at individual sites is created and the area inside the 10 m drawdown contour (where drawdown ≥ 10 m) is calculated. The total area is then compared to the drawdown footprint area given in the **compliance criteria**.

The **compliance criteria** footprint area was determined by hydrogeological modelling of the projected drawdown to 2036, the time period coinciding with the expiry of the **Special Water Licence** for Wellfield B, subject to any renewals. The model was calibrated to the current drawdown at the 95% confidence interval, and then drawdown was projected to 2036 using expected abstraction rates from the wellfield, and estimated pastoral usage and petroleum abstraction (Moomba) rates. The model used to determine the drawdown area was ODEX6, v1.

Significant differences exist between contours drawn using different computer codes/algorithms. The procedure below therefore defines and standardises the steps to be taken for generating and calculating the area within the 10 m contour, including steps to be taken when individual data points are not available.

3.1.2 Purpose

- Define a procedure for contouring of Wellfield B drawdown data.

3.1.3 Deliverable(s)

- A contoured drawdown map for Wellfield B.

3.1.4 Method

3.1.4.1 Nominated wells

Monitoring data, interpreted drawdowns and results from associated spring and environmental monitoring are reported in annual wellfield reports (AWR). The drawdown map as reported in the AWR for Wellfield B is constructed from the consideration of data from over 50 wells monitored either quarterly (mostly dedicated monitoring sites) or annually (typically pastoral abstraction wells). Drawdown is calculated at approximately 25 sites, the remainder being either flowing wells that cannot be shut in for pressure measurement, or wells for which no reliable reference pressure is available.

Although all wells are important for the construction of the drawdown map, some are crucial for the precise determination of the 10 m contour. These wells, to be termed nominated wells, are (see Figure 3-1):

- At least two of the three current Wellfield B production wells (GAB51, GAB52 and GAB53);
- Georgia;
- MB8;
- S5;

To ensure that sufficient data are available for contouring, BHP:

- Monitors nominated wells quarterly (see table 8.3);
- Maintains nominated wells in condition suitable for the precise determination of drawdown;
- Uses a minimum of 21 wells (inclusive of the nominated wells) with measured drawdown values to create the contours for any reporting period; and
- Provides a brief description, in the relevant AWR, on where and why drawdown values are absent and how the dataset on which the drawdown map is based could be improved.

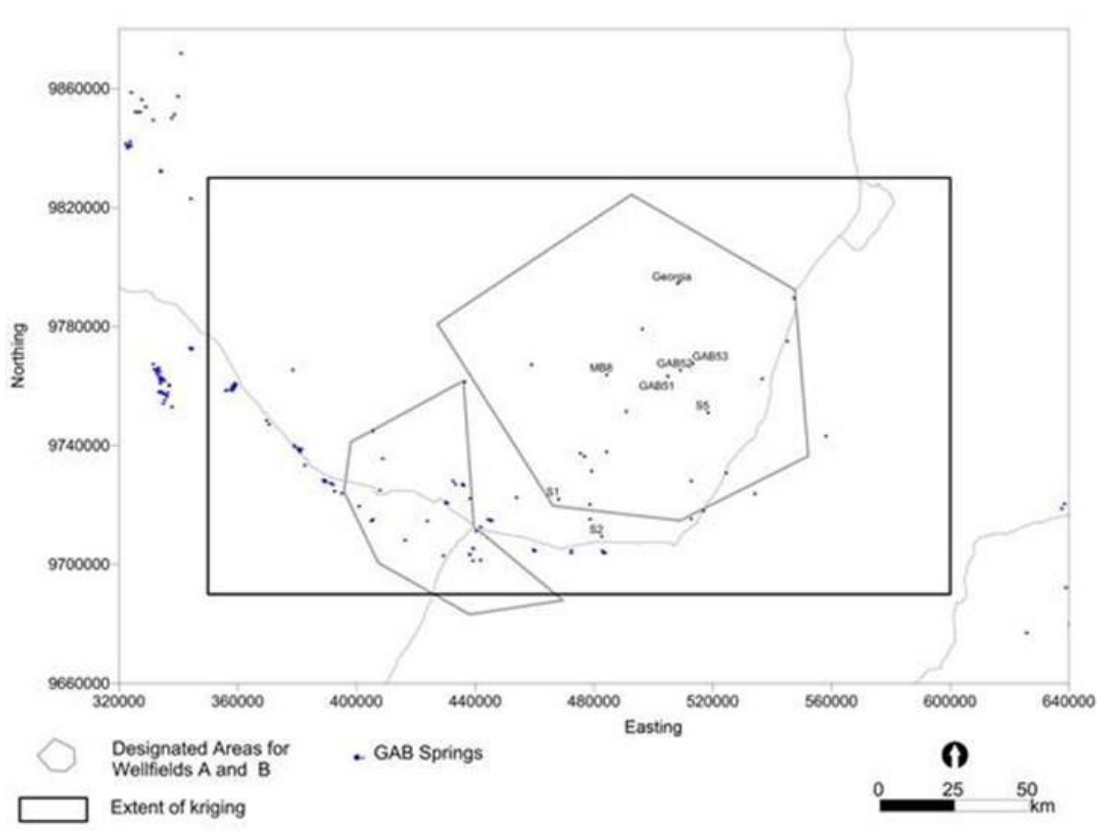


Figure 3-1: Extent of kriging area and nominated wells

3.1.4.2 Creation of drawdown map and 10 metre footprint area

Drawdown in an ideal confined aquifer is inversely proportional to the logarithm of the distance between the wellfield and the observation site. Drawdown contours are therefore dense near the wellfield and get sparse progressively further away, as opposed to an equidistance pattern. In order to account for the inverse logarithmic relationship, drawdowns are logarithmically transformed, processed and subsequently inverted back.

Computer based contouring algorithms begin by taking known data points (in this case the measured drawdown at monitoring wells) and interpolating values between these points onto the node points of a regular grid mesh. Additional interpolated points, known as control points, may also be added to the mesh to prevent induced effects usually caused by excessive extrapolation of values over large distances, or to reflect known geological and hydrogeological controls. The interpolated and known points are then used to generate the contour lines. While many different interpolation methods are available, kriging has been chosen as the preferred method. Kriging is a well-known and widely used geostatistical method developed in the 1960s and is now used in many areas of science. It is considered one of the best mathematical methods and produces what are known as 'linear unbiased' estimates.

The coordinate system used for gridding and contouring in the wellfield is based on a Lambert projection, centred on the wellfield area. Lambert projection has become a standard projection for mapping large areas in mid-latitudes such as Australia, and is the preferred projection in these areas (Intergovernmental Committee on Surveying and Mapping, 2012)

The step by step process is:

1. Calculate drawdown (d) at each site using the mean of the 12 months preceding the reporting period (for the production bores GAB51–GAB53 use mean flow pressure instead of shut-in pressure when calculating drawdowns). The mean may be calculated from four quarterly measurements or may be equal to the single measurement for sites monitored annually. Where data are not available or anomalous, derive an alternative value using the procedure at section 3.1.4.3 (Anomalous values).
2. Where required, to honour hydrogeological considerations and prevent artefacts in the contouring, control points may be added. Any added control points will be clearly identified on the map presented in the AWR, together with an explanation of the justification for such points.
3. Calculate the ten-based logarithm ($\log_{10} d$) of drawdowns for each site. For zero drawdown, use the small value of 0.01 m in order to create the logarithm.
4. Use point kriging to grid the logarithmic drawdown data, then contour the gridded data with the following parameters (see Figure 3-1):
 - Cell size: 1 km by 1 km
 - Spatial extent (Wellfield Lambert projection):
 - a. Easting minimum: 350000, Easting maximum: 600000;
 - b. Northing minimum: 9690000, Northing maximum: 9830000.
5. Invert the logarithmic drawdown contours back to linear contours by raising the values to the power of ten.
6. Present drawdown contours in the annual wellfield report (AWR) and the area inside the 10 m drawdown contour line, including labels for individual sites with the calculated drawdown.

3.1.4.3 Anomalous values

High frequency natural temporal changes in potentiometric level (groundwater head) in the GAB in the vicinity of Wellfield B are not expected, due to the confined nature of the aquifer, little if any vertical recharge and the distance from recognised recharge areas. Most temporal changes in the order of months or years are therefore related to abstractions from wells and errors or uncertainties. Accurate groundwater heads and drawdowns from Wellfield B are expected to show only gradual changes in time. It is crucial that drawdown is calculated and reported as accurately as possible and anomalous groundwater head values are excluded from subsequent processing and drawdown calculation.

A data recovery priority (see section 3.3.4 and section 9, Appendix D) is allocated to all monitored sites within the wellfields region to facilitate follow-up when unforeseen circumstances (e.g. extensive rainfall in the region) result in a disruption to the data collection field run, or when an assessment near the time of collection indicates that the data may be unreliable. For the second quarter of each year, coinciding with the June annual monitoring run, every bore is assigned a data recovery priority of one, requiring the data to be collected as soon as possible if unavailable for some reason. Other than exceptional circumstances, this would normally mean a return visit to the well to ensure that data is available for the annual report.

Anomalous values are defined as those inconsistent with the pattern of drawdown reasonably expected from Wellfield B. This may be due, but not limited to:

- The loss of well integrity;
- Physical damage to the well;
- Uncontrolled flow;
- Abstraction from the well itself or from a nearby well;
- Inconsistent operating conditions.

Where an anomalous value is obtained, the cause is investigated and, for nominated wells if necessary, a schedule for repair or replacement is finalised as described in section 3.1.4.6 (Investigation of anomalous values).

The procedure to be followed to obtain an alternative value in the event of an anomalous value is shown diagrammatically in Figure 3-2 and described below.

3.1.4.4 Nominated wells

1. Exclude anomalous value and provide reasons for the exclusion in the AWR. In relevant sections of the AWR, refer to the drawdown as estimated.
2. Calculate the mean of the remaining reliable (non-anomalous) values for the well for the 12 months previous to the reporting period. For example, if one value is anomalous, calculate mean drawdown from the remaining three values for the well. If no reliable value is available for the 12 months previous to the reporting period estimate drawdown using one, or a combination, of the methods listed below (in the order of preference, from highest to the lowest):
 - a. estimate from the drawdown vs log time/distance² (from Wellfield B) method (nominated wells are situated close to Wellfield B where the aquifer approximates an 'ideal' confined aquifer for which the drawdown is expected to be proportional on a semi-log scale to time/distance²; and proportional to the logarithm of time since abstraction began).
 - b. Estimate from the drawdown vs log distance (from Wellfield B) method.
 - c. Estimate drawdown from another site with a demonstrated strong correlation.
 - d. Use numerical modelling results where there is demonstrated strong calibration for the appropriate site.

3.1.4.5 Non-nominated wells

1. Exclude anomalous value and provide reasons for the exclusion in the AWR.
2. For sites monitored quarterly, calculate the mean of the remaining reliable (non-anomalous) values for the well for the 12 months previous to the reporting period. For example, if one value is anomalous, calculate mean drawdown from the remaining three values for the well. If no reliable value is available for the 12 months previous to the reporting period, use the last reliable measurement if that was taken within 15 months previous to the reporting period. If no reliable value is available for the 15 months previous to the reporting period exclude the appropriate site data from the contouring process for the reporting period.
3. For sites monitored annually, use the last reliable measurement if that was taken within 15 months previous to the reporting period. If no reliable value is available for the 15 months previous to the

reporting period, exclude the appropriate site data from the contouring process for the reporting period and note the exclusion.

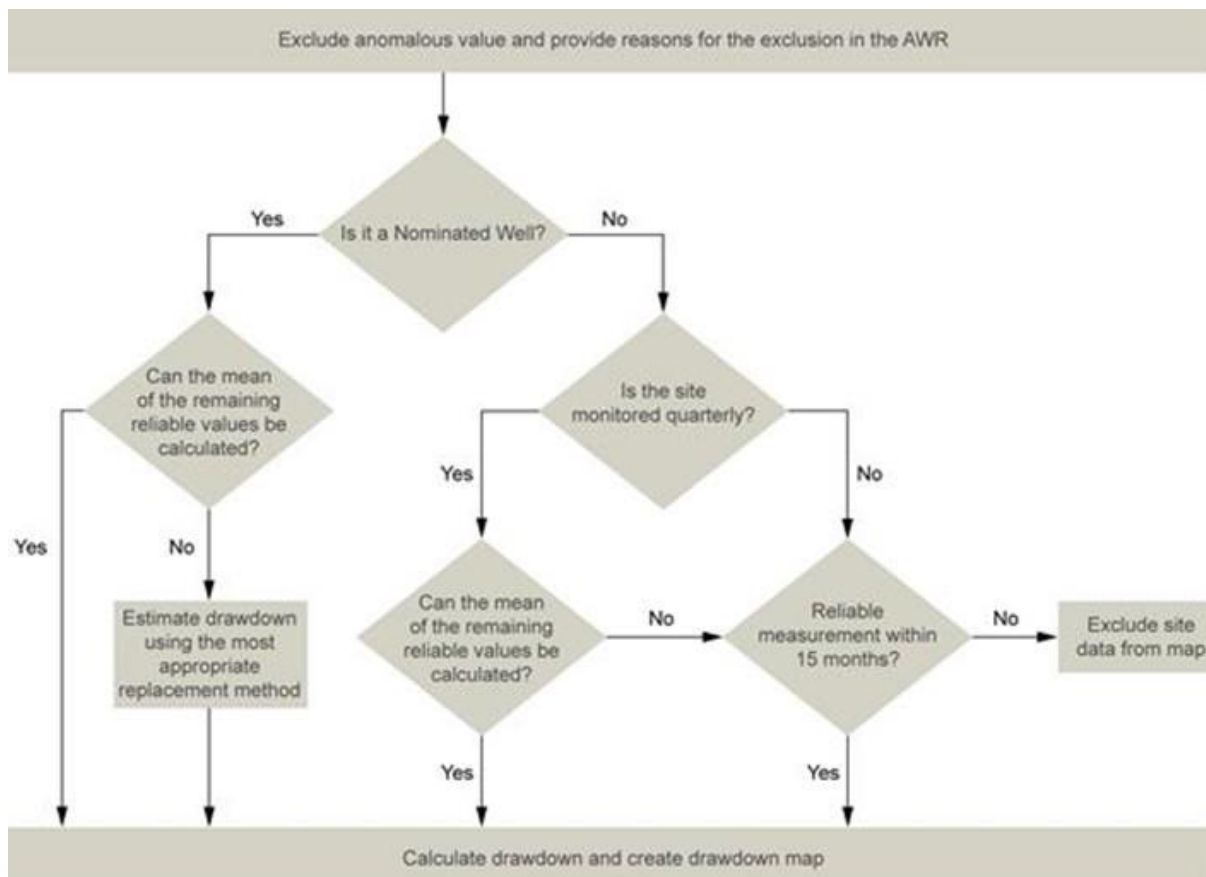


Figure 3-2: Procedure if anomalous value is measured

3.1.4.6 Investigation of anomalous values

When an anomalous value is obtained, the following response measures may be taken. This is a general guide to the sequence of events, since not all steps may be required:

1. Where data is missing, check reasons and attempt to obtain the data. Data may sometimes be missing as a result of access issues, weather or similar reasons, and in these cases it is usually possible to re-attempt data collection.
2. Confirm and review data integrity. This will ensure that the observations are real and not an artefact of methodology, measurement error, calibration, etc. Measuring equipment should be inspected and re-calibrated. All sequences of data transfer from field sheets to database and any calculations should be confirmed.
3. Increase monitoring intensity and/or frequency in the area where the anomalous value was obtained. Increased monitoring helps to verify interpretation of data and determine any causal relationship with water extraction from the well itself or other nearby wells.
4. Confirm and review well integrity. This helps to ensure that the well itself is sound and has no issues that may lead to anomalous values. Well integrity may be checked by obtaining well history and logging details, conducting well tests including pump tests, down-hole logging and other available methods.

Where possible, investigation of anomalous values is carried out within six months. For nominated wells, if investigations indicate that well integrity or a failure of the well is the cause of the anomaly, an assessment is made (in consultation with the State Government) as to whether the well remains necessary for

assessment of compliance. If so, the well is rehabilitated, substituted or replaced within 24 months, with all efforts made to achieve this within 12 months.

3.2 Aquifer water quality

3.2.1 Background

Minor shallow aquifers containing saline water (20,000–50,000 milligram per litre (mg/L) TDS) occur in the vicinity of Wellfields A and B. A reduction in aquifer pressures caused by abstraction could conceivably change flow paths and potentially affect water quality in the main GAB aquifer.

Water expressed at GAB springs is generally more saline than that obtained from GAB wells, suggesting that, in many situations, GAB spring flow is a mixture of ground water from the main GAB aquifer and local shallow aquifers, influenced by evaporative processes. A change in aquifer pressure could potentially change the mix ratios and affect the water quality, however drawdown in the vicinity of GAB springs is expected to be small and it is likely that any change in water quality parameters will be negligible. Aquifer pressures are very high in the vicinity of Wellfield B, making it unlikely that water quality will be affected in this area.

Electrical conductivity (EC) is considered the most valuable water quality character for detecting a change in flow paths or leakage from overlying aquifers. Assessment of water quality is therefore concentrated on EC data. Other water quality parameters such as pH and temperature are measured but less emphasis is applied to routine assessment of these data. However, pH and temperature data may be used as part of cause analysis if a change in conductivity is linked to water extraction from the Olympic Dam Wellfields.

3.2.2 Purpose

- Quantify by routine and appropriate methods, water qualities in all monitoring and production wells on a quarterly basis, as stated in the **Indenture**.
- Identify any changes in EC at bores and springs in the region of either Wellfields A or B that, combined with other influencing factors, may be attributed to abstraction.
- Provide data to support the **leading indicator** for GAB impacts, and alert management when levels approach the **leading indicators**.

3.2.3 Deliverable(s)

- Records of GAB water EC, pH and temperature data for assessment of changes and trends in water quality.

3.2.4 Method

GAB spring, production and monitoring bore water quality analyses are conducted in the field. Water quality parameters assessed include pH, EC and temperature of flowing water using a calibrated field lab.

Samples of GAB springs in the wellfields region are measured for water quality annually (see section 9 Appendix D, Table 9.4; Figure 6-3)

Water quality analyses of GAB waters are conducted on a routine basis ranging from quarterly to annual (see Table 9.1). The analysis of bore water chemistry that includes anions and cations is undertaken only if significant deviations in conductivity and/or pH are recorded as a part of root cause analysis. A comprehensive baseline exists for the elemental composition of waters within the wellfields region to allow interpretation, should it be required.

The **Indenture** requires assessment of water quality from monitoring and production bores each quarter. Water quality data are collected from all monitoring bores where the potentiometric head is above the bore head to allow purging of the bore prior to sample collection (see Table 9.1). Water quality data are not collected from sub-artesian (potentiometric head below bore head) bores as artificial pumping is required and it is considered that there is a sufficient number of monitoring sites to allow detection of any changes in water quality. Any new bores drilled within the wellfields region will be sampled and submitted for detailed water chemistry analysis to determine baseline information.

Analysis of EC data is used as the primary indicator of changes in water quality at bores and GAB springs within the wellfields region, by identifying sites with anomalous trends in EC. In the event that any anomalous trends are identified, investigations will be undertaken to determine why a change has occurred, the potential effects of that change, and if it can be linked to water abstraction from Wellfields A or B.

3.3 GAB aquifer potentiometric head

3.3.1 Background

The GAB is an artesian water resource over much of its area, resulting in bores which intersect the aquifer flowing at the surface without the aid of pumps. In some areas of the GAB the wellhead pressure is sufficient to provide extensive water reticulation networks more than 100 km long. Abstraction of water from the GAB reduces artesian pressure and has the potential to affect existing users and GAB spring flows.

Drawdown of artesian pressure is the most direct and important measure of impact on the GAB due to water abstraction. Agreed compliance criteria for drawdown have been established for Wellfields A and B.

3.3.2 Purpose

- Quantify by routine and appropriate methods water pressures and water levels in all monitoring and production wells, and at the boundary of the **Designated Areas**, as agreed with the state.
- Measure or infer the magnitude of the drawdown according to the relevant **compliance criteria** for Wellfields A and B.
- Provide data to support the **leading indicator** for GAB drawdown, and alert management when levels approach the **leading indicator** value.

3.3.3 Deliverable(s)

- Records of artesian pressure and groundwater level data for assessment of drawdown.

3.3.4 Method

Artesian pressure or water level is determined at approximately 50 bores within the vicinity of Wellfield A and approximately 52 bores within the vicinity of Wellfield B (see section 9, Appendix D). Bore monitoring frequency is dependent on the location, bore type and location of other bores in the vicinity (see Table 9.1), as well as the extraction rate of water from Wellfield A.

Abstraction of water from Wellfield A locally reduces artesian pressure around the points of abstraction and in some circumstances has the potential to affect environmental flows to artesian springs particularly in the north east sub-basin (NESB). At monthly average abstraction rates greater than 5ML/d, monitoring of wells and selected spring flows in the NESB will occur monthly (Table 9.5).

Wellhead pressure is measured using calibrated pressure transducers. Where the potentiometric pressure is below the wellhead (i.e. the bore is non-artesian), the depth to the water level is measured. All measurements of pressure and depth to water are corrected to a fixed elevation point of reference for each bore.

For Wellfield B, drawdown is calculated either as a pressure loss from reference pressures (PRPs) established for each of the bores monitored, or as a difference between contemporary and estimated 1996 practical reference heads (PRHs) for monitoring bores that are measured 'cold' (for example MB5–8, Jackboot Bore and D2). 'Cold' wellhead pressure and near surface temperature measurements are those unaffected by antecedent flow.

For Wellfield A, drawdown is calculated as the difference between reference groundwater elevation (at the time of granting of the Special Water Licence) and the present groundwater elevation (expressed as metres Australian Height Datum based on gauge pressure or groundwater level measurements).

Near Wellfield A, bores are generally shallow (<200 metres (m)) and temperature is low (<40°C) and therefore the changes in water density with temperature effects are not significant. For the deep bores near Wellfield B, significant variation in temperature, and hence groundwater density, occurs between the aquifer and measurement point on the land surface. As a result of this complex physical relationship, PRPs may be

subject to review and revision as understanding of hydrogeological processes evolve and the influence of temperature on water density and hydraulic head is more clearly understood.

A data recovery priority (see section 9, Appendix D) is allocated to all sites monitored within the wellfields region to facilitate follow-up when unforeseen circumstances (e.g. extensive rainfall in the region) result in a disruption to the data collection field run, or when an assessment near the time of collection indicates that the data may be unreliable. A follow-up priority of 1 ('as soon as possible') indicates that readings should be taken as soon as an anomalous reading has been identified or the circumstances that led to the reading not being taken have been corrected, and certainly prior to the next scheduled (quarterly) run. A priority of 2 ('next scheduled monitoring run') indicates that readings can be left until the next run or an opportunistic reading can be taken. Due to the importance of obtaining an end-of-year reading for annual compliance assessment, and for pastoral bores that are monitored only on an annual basis, priorities are given for data recovery in the first, third and fourth quarterly periods, and separately for the second quarter.

3.4 GAB spring flow

3.4.1 Background

Water abstraction from the GAB has the potential to reduce the flow of water from springs in the vicinity of a wellfield. Predictions of the extent of flow reductions due to the operation of Wellfields A and B were made in the 1984 and 1997 environmental impact statements and updated in 2016 (Kinhill-Stearns Roger 1982; Kinhill Stearns 1984; Kinhill Engineers 1997a, 1997b, Golder Associates 14766004-019-M-Rev2), and are presented in Appendix E.

Reduced flow at GAB springs may reduce the area of habitat available to organisms or it may increase the rate of spring extinctions.

3.4.2 Purpose

- Determine the extent of flow change at GAB springs within each hydrogeological zone of impact that may be attributed to water abstraction from Wellfields A and B.
- To provide data to support the **leading indicator** for GAB impacts, and alert management when levels approach the **leading indicator** value.

3.4.3 Deliverable(s)

- Records of spring flow data for assessment of flow trends and possible drawdown impacts.
- Triennial qualitative comparison of GAB spring monitoring data incorporating GAB spring flow, GAB springs vegetation composition, and GAB springs endemic invertebrate monitoring.

3.4.4 Method

Spring flow is naturally variable and inherent conditions make accurate flow measurements difficult. However, regular measurements at numerous springs over a significant period of time provide indicative flow trends.

Spring flow measurements are taken from approximately 42 springs in the wellfield region (see Table 9.4). Spring flow is measured by weir gauging, or by using a container of known volume and a timer. Flow measurement technique depends on vent and flow channel characteristics. Flow monitoring data are collected annually (see Table 9.1). Where flow is not measured, presence or absence of flow is recorded at all spring vents within the program.

3.5 Efficiency of water use

3.5.1 Background

The efficiency of water use is a significant driver in minimising the impacts of water abstraction from the GAB. Efficient water use at the operation and at the associated townships and accommodation villages (including Andamooka) is promoted through education and engineering controls. Targets and key performance indicators are developed to promote continuous improvement in water use efficiency. An efficiency rate of 1.24 kilolitre per tonne (kL/tonne) of ore milled was anticipated (in the 1997 EIS) by 2002

(Kinhill Engineers 1997a). The EIS provides ODC with improved efficiency of water use and supply practices.

The **Indenture** requires ODC to:

- Document the volume of water abstracted from the GAB; and
- Annually provide a budget of expected water use each year for the next 10 years.

3.5.2 Purpose

- Measure the industrial water use efficiency of the operation and total potable water use of associated townships and accommodation villages, including Andamooka.
- Quantify by routine and appropriate methods total water quantities withdrawn from any wellfield on both an individual well and wellfield basis, with abstraction added to the record on a monthly basis, as required by the **Indenture**.
- Provide a 10-year forward schedule for abstraction of groundwater from the GAB.

3.5.3 Deliverable(s)

- Collated domestic and industrial water use efficiency data, to assess performance against **improvement targets**.
- Ten-year water use schedule to be submitted to the Indenture Minister by 1 January annually.

3.5.4 Method

Water use from the GAB is metered at a number of locations to enable a balance between total abstraction and plant and domestic usage to be obtained. Flow meters record the volume of water extracted from all production bores at the wellfields and the volume delivered to site via the M1 and M6 pipelines. Potable water use for the associated townships and accommodation villages, including Andamooka, is recorded by registered meters.

Industrial water use efficiency is assessed by determining the volume of GAB water used per tonne of material milled on a monthly basis. The volume of water used applies to GAB water only and excludes any additional inputs from sources such as stormwater, mine water and local saline supply. The volume of GAB water differs from the total wellfield abstraction, as it excludes pastoral use, pipeline losses and domestic potable supply. The amount of off-site potable water used is determined as the mean daily use over a 12-month period. Off-site water use varies considerably between summer and winter.

The 10-year schedule of the best estimate of the annual daily average requirement for GAB water as supplied to the minister is based on predicted production rates and the savings generated by water conservation efforts.

4 COMMITMENTS

4.1 Reporting

Clause 13 of the **Indenture** requires ODC to prepare an annual Wellfields Report that is submitted to the Indenture Minister. The annual Wellfields Report is included as an attachment to the annual EPMP report, to cover the GAB reporting requirements of the Environmental Protection and Management Program (EPMP).

The report is prepared by a competent hydrologist or hydrogeologist and address the use of aquifers and future water exploration, development, production and management. The report includes details of:

- Total abstraction and individual well abstraction on a monthly basis;
- Water pressure and levels in monitoring and production wells;
- Water quality at monitoring and production wells on an annual basis.

The Environmental Assessment Report (Environment Australia et al. 1997) of the 1997 Environmental Impact Statement provides recommendations by both the Australian and state governments (recommendations 1d and 6 respectively) for continuation and reporting of wellfield and GAB spring monitoring programs. Results are to be reported to the Olympic Dam Environment Consultative Committee (ODECC) and the GAB Coordinating Committee. In addition, recommendations 1b and 4 require monitoring data to be collected and used to periodically update modelling. On the basis of this obligation, Olympic Dam committed to the ODECC to review the calibration of the GAB groundwater model every three years.

4.2 Summary of commitments

Table 4-1: Summary of commitments

Action	Parameter	Frequency
Monitor	GAB spring and artesian bore water quality	Quarterly – Annually
Monitor	Artesian water pressures and water levels from bores in the wellfields region	Quarterly – Annually
Monitor	GAB spring flow rates in the wellfields region	Annually
Monitor	Volume of water abstracted from the GAB	Monthly
Monitor	Water usage efficiency for operation and off-site	Monthly
Monitor	NESB artesian pressure and spring flow	Monthly while Wellfield A Abstraction >5 ML/d
Employ	A hydrogeologist or hydrologist and sufficient qualified staff to undertake the requirements of the GAB MP	Ongoing
Assess	Hydrogeological model by undertaking calibration check and recalibration if required	Triennially
Report	Monitoring results in the Wellfields Report to the Minister for Mineral Resources Development	Annually
Report	Estimated drawdown effects at spring groups to the Olympic Dam Environment Consultative Committee and the Great Artesian Basin Coordinating Committee	Annually
Report	A 10-year schedule of the best estimate of the annual daily average to the minister	1 January of every year
Report	Monitoring results in the annual EPMP report to the Indenture Minister	Annually
Review	The GAB MP and modify as appropriate	Annually

5 DEFINITIONS AND REFERENCES

5.1 Definitions

Throughout the EPMP some terms are taken to have specific meaning. These are indicated in bold text in the documentation and are defined in the glossary in section 3 of the EMM. Defined terms have the same meaning wherever they appear in bold text. Some other terms and acronyms are also defined in the glossary, but do not appear in bold text.

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6 APPENDIX A: WELLFIELDS LOCATION PLANS

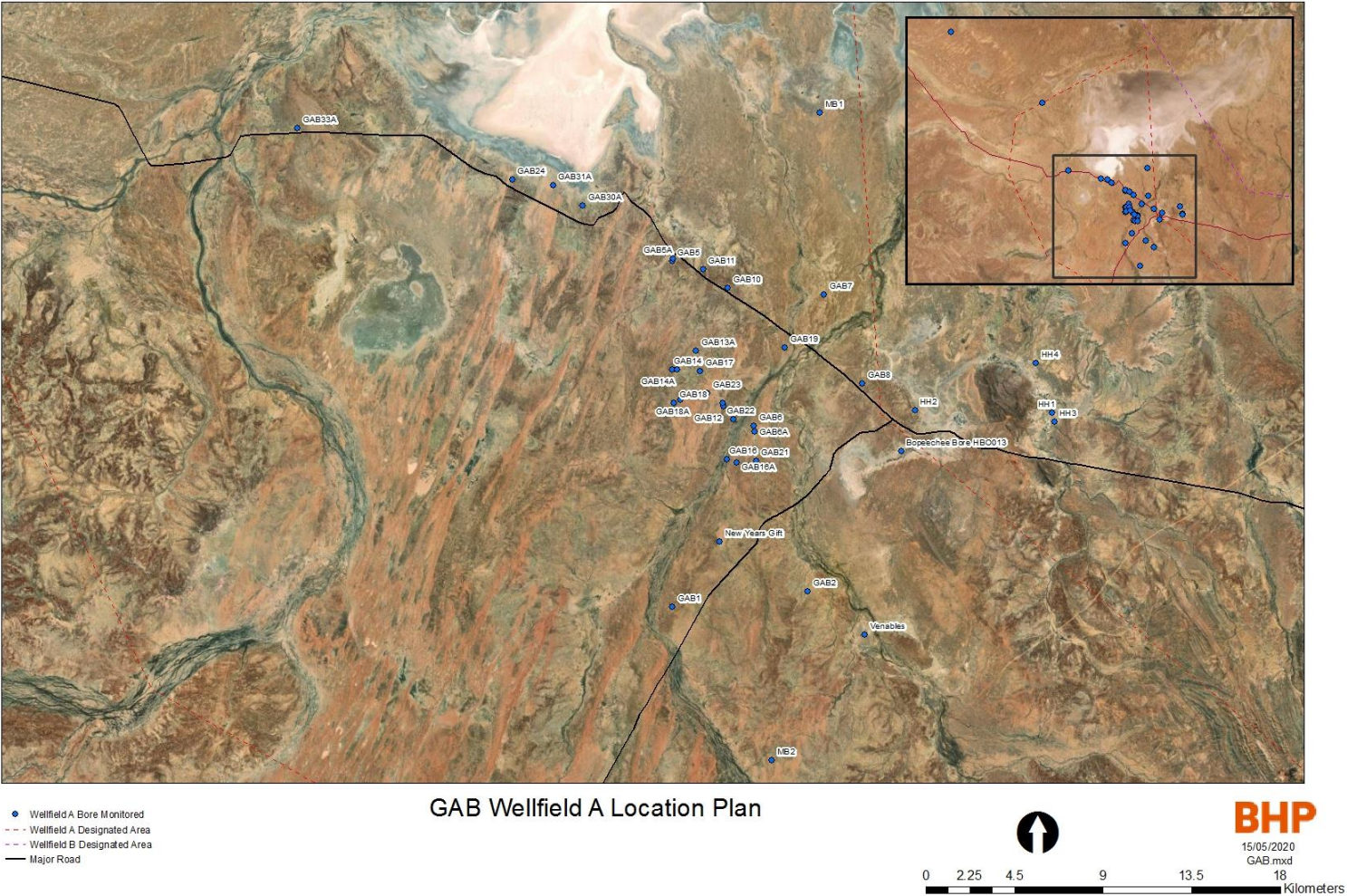


Figure 6-1: GAB Wellfield A location plan

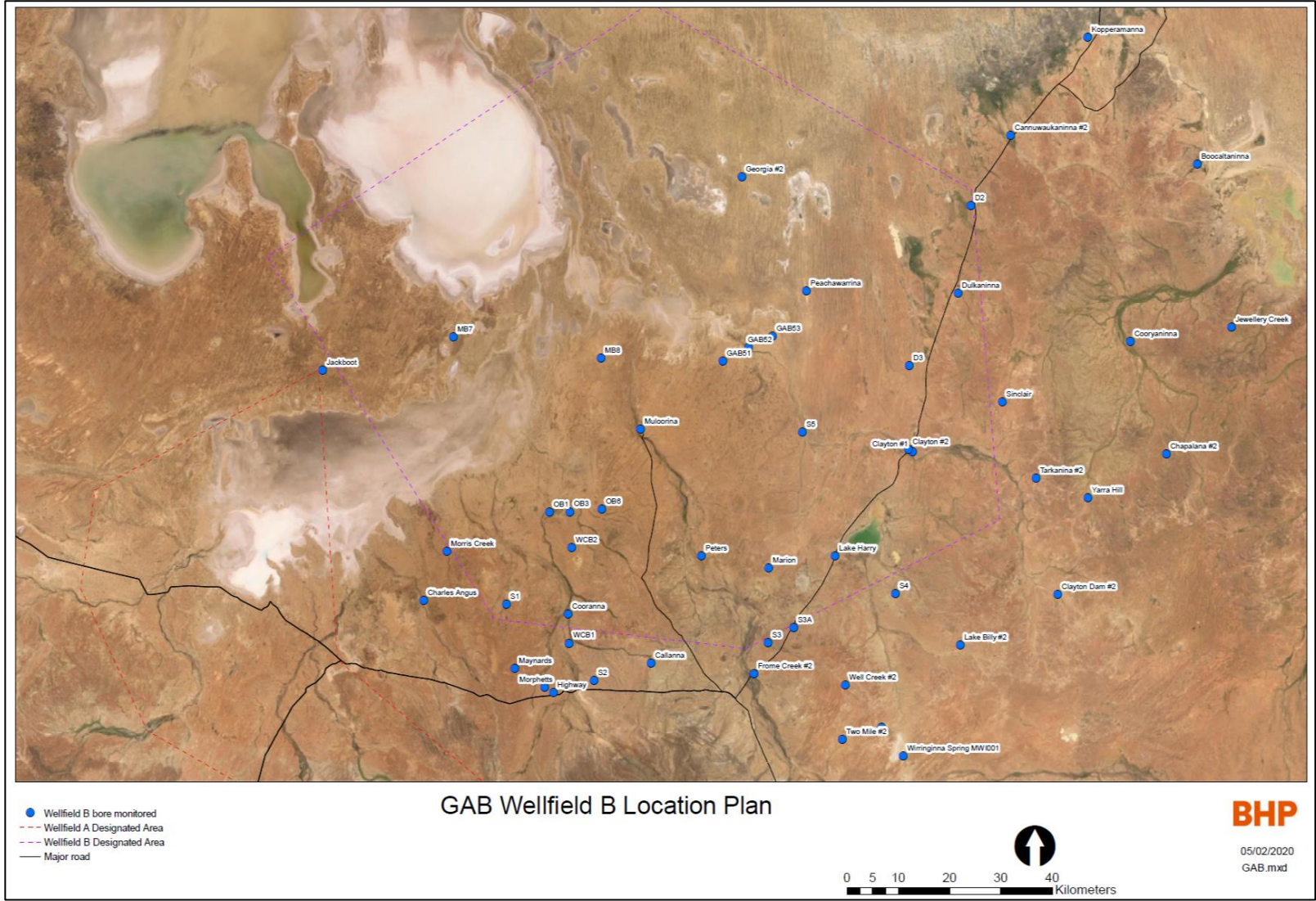


Figure 6-2: GAB Wellfield B location plan

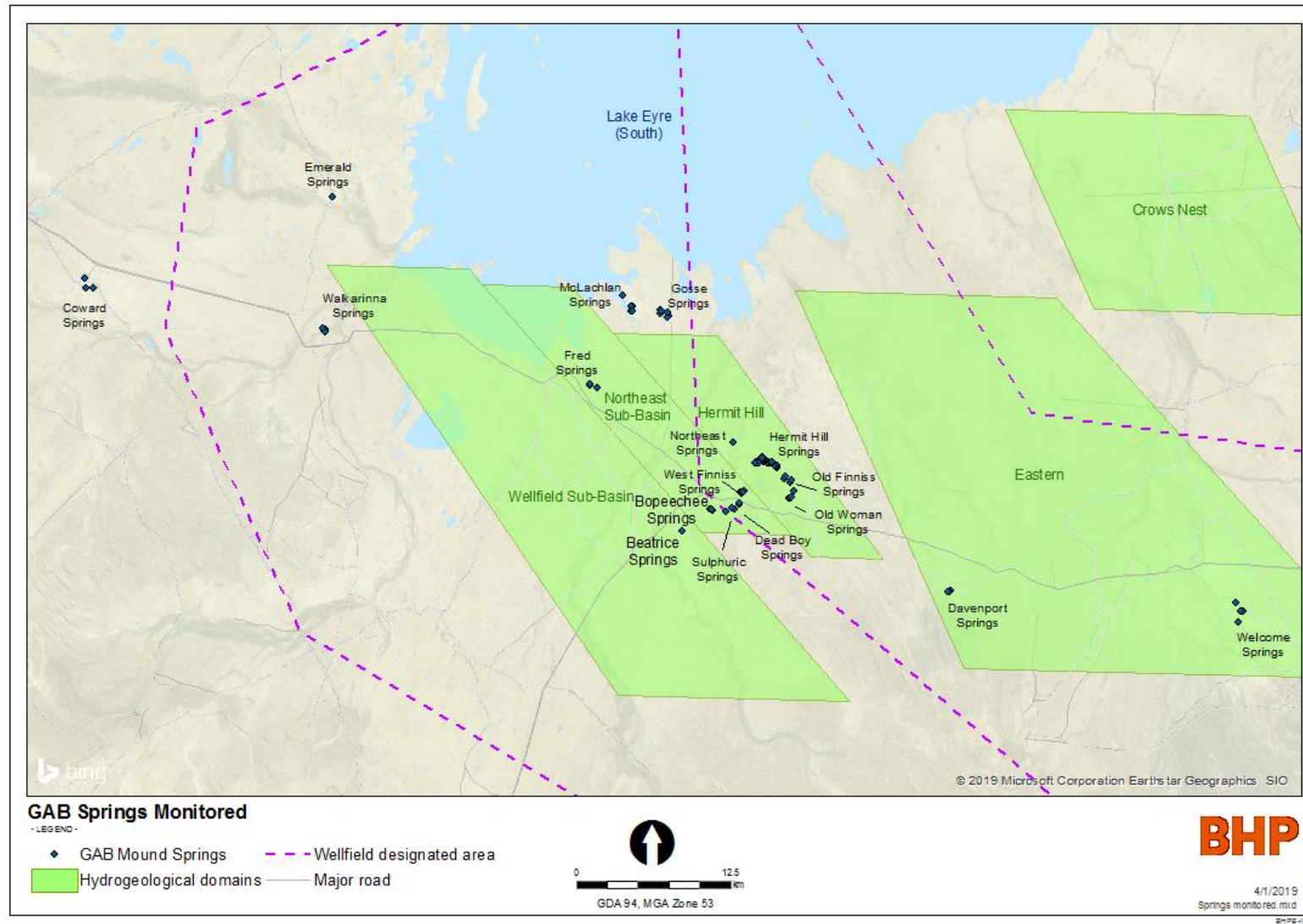


Figure 6-3: Wellfields A and B monitored spring groups.

7 APPENDIX B: BACKGROUND HYDROGEOLOGY OF THE GAB

The GAB is a subterranean water resource underlying some 22 per cent of the Australian continent (Cox and Barron 1998). Recharge occurs mainly along the eastern edge of the basin, with a smaller recharge area along the western edge. The aquifer is confined beneath an impermeable layer and pressure is sufficient throughout most of the basin to allow bores to free-flow at the surface (Habermehl 1983).

The environment of the wellfield region is arid, with maximum summer temperatures often exceeding 40°C. Vegetation communities in the region reflect this by consisting of species typically adapted to hot, dry conditions.

Located along the south-western margins of the GAB are numerous GAB springs, which are natural upwellings of artesian water at the surface. Springs are generally located along the margins of the GAB where the confining bed of rock tends to be thin and close to the surface (Habermehl 1983).

GAB spring assemblages form permanent aquatic environments, which support an array of plants and animals adapted to these aquatic habitats in an otherwise arid landscape. Many of the plants and animals present in GAB springs are nationally and internationally recognised as rare or threatened species.

Abstraction of water from the GAB generates a cone of drawdown around the point or area of abstraction. Reduction in aquifer pressure subsequently reduces the amount of surface flow at GAB springs and pastoral bores within the cone. The volume and direction of water flowing from GAB springs varies considerably over time due to a number of natural processes (Fatchen and Fatchen 1993). In addition, flow rates of GAB springs are difficult to obtain and data interpretation can be complex (Harris 1992). Monitoring of flow rates at GAB springs cannot be relied upon solely for determining impacts of water abstraction. By monitoring the extent of the cone around production bores and combining this with GAB spring and pastoral bore flow rate data, regional impacts can be more readily assessed. Modelling of the cone assists in the prediction of impacts from changes in abstraction rates.

In addition to impacting GAB spring flow rates, localised reduction in aquifer pressure may alter aquifer flow paths and cause mixing with local groundwater (Kinhill-Stearns 1984). This can result in a localised change in water quality in the aquifer. While the water chemistry of GAB springs varies considerably, some GAB springs flora and fauna have specific water quality requirements (Kinhill-Stearns 1984).

A pastoral industry operates throughout much of the GAB area in Australia and relies on water from the basin for stock supplies. Artesian pressure is often utilised to distribute water in pipelines and occasionally to generate power for remote homesteads. Reduction in aquifer pressure may affect the capacity of a pastoral operation to distribute stock water.

8 APPENDIX C: HISTORY OF DEVELOPMENT OF THE OLYMPIC DAM WELLFIELDS

Abstraction from Wellfield A commenced in August 1983 from a single production bore (GAB 6) at a rate of 1.3 megalitre per day (ML/d). The production bores GAB 12, GAB 14, GAB 15, GAB 16 and GAB 18 came into full production during mid-1988 to meet the water requirements (approximately 9 ML/d) for the initial development phase of the operation. Production bores GAB 30 to 32 were commissioned in January 1992 to meet the water requirements of approximately 15 ML per day for an early expansion phase of the operation. Continued increases in production led to an anticipated increase in water requirements of up to 17 ML/d over the summer of 1995 – 1996 (Kinhill Engineers 1995). By the summer of 1998 – 1999 abstraction had reached 20 ML/d.

Wellfield B came into operation as the main supply of GAB water during September 1996 to meet increases in demand associated with the expansion of production at Olympic Dam, and to reduce the amount of abstraction from Wellfield A. Initially water was supplied from a single production bore (GAB 51) at a rate of about 12 ML/d. In December 1998 GAB 52 and 53 were commissioned and incorporated into the supply from Wellfield B (Figure 8-1).

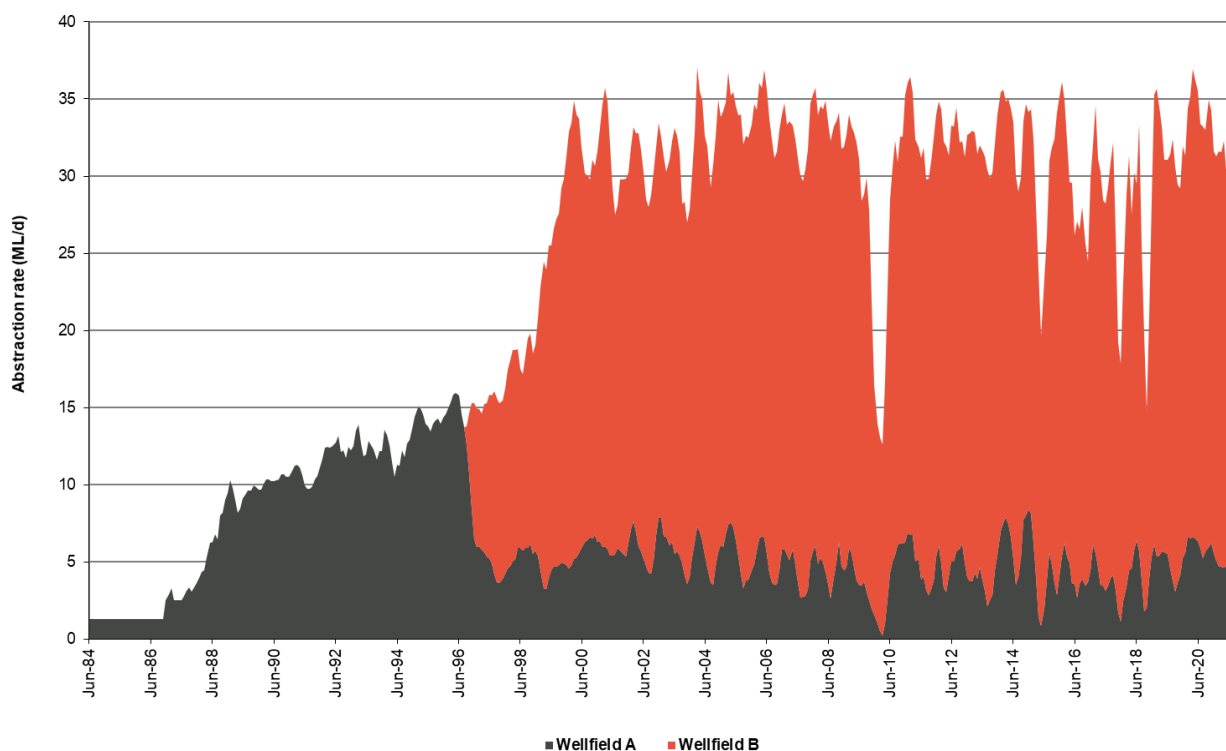


Figure 8-1: Historical abstraction from Wellfields A and B

9 APPENDIX D: MONITORING TABLES FOR BORES AND SPRINGS IN WELLFIELDS A AND B

Table 9.1: Summary of bore monitoring frequency

Bore type	Category	SIP or SWL	Flow pressure	Flow rate	Water quality
Production bores (Wellfield A)	ProdAQ			Continuous	Quarterly
Production bores (Wellfield B)	ProdBQ		Quarterly	Continuous	Quarterly
Monitoring bores	MQ	Quarterly	Quarterly	Annually	Quarterly
Sub-artesian observation	SubQ	Quarterly			
Shallow observation	SQ	Quarterly			
Pastoral bores	PQ	Quarterly	Quarterly	Annually	Quarterly
Pastoral bores	PA	Annually	Annually	Annually	Annually
Springs	LUC			Annually	Annually

Notes:

- At some pastoral bores shut-in pressure (SIP) or flow pressure may not be obtained because of unsuitable wellhead configuration.
- SIP: borehead pressure when the valves are closed and the bore is shut-in. Measurement is relative to antecedent flow conditions (conditions prior to shut-in), gauge position and shut-in duration.
- SWL: standing water level is the water level in a bore that is not being affected by water abstraction or pumping.
- Flow pressure and flow rate for monitoring bores collected only where bore is flowing on arrival.
- Monitoring period quarters and per financial year

Table 9.2: Monitoring for bores in the Wellfield A Region

Bore name	Unit number	Priority		Bore category
		Q1, Q2, Q3	Q4	
Bopeechee HBO013	6338-6	2	1	PQ
GAB 1	6338-27	2	1	MQ
GAB 2	6338-31	2	1	SubQ
GAB 5a	6338-36	2	1	MQ
GAB 6	6338-22	2	1	ProdAQ
GAB 6a	6338-23	2	1	MQ
GAB 6s	6338-70	2	1	SQ
GAB 7	6338-24	2	1	MQ
GAB 8	6338-44	1	1	MQ
GAB 10	6338-46	2	1	MQ
GAB 11	6338-47	2	1	MQ
GAB 12	6338-57	2	1	ProdAQ
GAB 12a	6338-50	2	1	MQ
GAB 12s	6338-76	2	1	SQ
GAB 13a	6338-51	2	1	SubQ
GAB 14	6338-58	2	1	ProdAQ

Bore name	Unit number	Priority		Bore category
		Q1, Q2, Q3	Q4	
GAB 14a	6338-52	2	1	MQ
GAB 14s	6338-77	2	1	SQ
GAB 16	6338-60	2	1	ProdAQ
GAB 16a	6338-54	2	1	MQ
GAB 16s	6338-79	2	1	SQ
GAB 17	6338-55	2	1	SubQ
GAB 18	6338-61	2	1	ProdAQ
GAB 18a	6338-56	2	1	SubQ
GAB 18s	6338-80	2	1	SQ
GAB 19	6338-63	2	1	MQ
GAB 21	6338-66	2	1	SubQ
GAB 21s	6338-67	2	1	SQ
GAB 22	6338-65	2	1	SubQ
GAB 22s	6338-68	2	1	SQ
GAB 23	6338-64	2	1	SubQ
GAB 23s	6338-69	2	1	SQ
GAB 24	6339-12	2	1	MQ
GAB 30a	6338-71	2	1	MQ
GAB 31a	6338-72	2	1	MQ
GAB 33	6339-15	2	1	MQ
HH 1	6338-38	2	1	MQ
HH 2	6338-39	1	1	MQ
HH 3	6338-40	2	1	SubQ
HH 4	6338-42	2	1	MQ
MB 1 (Gosse)	6339-9	2	1	MQ
MB 2	6338-49	2	1	SubQ
MB5	6339-55	2	1	MQ
MB6	6239-759	2	1	MQ
New Years Gift	6338-2	2	1	PQ
Venables	6338-33	2	1	SubQ

Notes:

- Interpretation of category codes is provided in Table 9.1.
- Priority refers to data recovery level if unforeseen circumstance results in missed data: 1 – As soon as possible; 2 – Next scheduled monitoring run. Refer to section 3.3.4 for further details.
- Occasionally a bore may be excluded from the MP due to bore structural failure, a change in operation or other unforeseen circumstance.

Table 9.3: Monitoring for bores in the Wellfield B Region

Bore name	Unit number	Priority		Bore category
		Q1, Q2, Q3	Q4	
Boocaltaninna	6640-20	N/A	1	PA
Brolga (Highway)	6438-92	N/A	1	PA
Callanna	6438-95	N/A	1	PA
Cannuwaukaninna 2	6640-4	N/A	1	PA
Chapalanna 2	6639-19	N/A	1	PA
Charles Angus	6438-1	N/A	1	PA
Clayton	6539-2	N/A	1	PA
Clayton 2	6539-9	N/A	1	PA
Clayton Dam 2	6639-21	N/A	1	PA
Cooranna	6438-4	2 (Q2 only)	1	PQ
Cooryanna 2	6639-16	N/A	1	PA
D2	6540-15	1	1	MQ
D3	6539-17	2	1	MQ
Dulkaninna 2	6539-14	N/A	1	PA
Frome Creek 2	6538-210	N/A	1	PA
GAB 51	6539-19	2	1	ProdBQ
GAB 52	6539-20	2	1	ProdBQ
GAB 53	6539-18	2	1	ProdBQ
Georgia 2	6540-16	1	1	PQ
Jackboot	6339-6	1	1	PQ
Jewellery Creek	6639-17	N/A	1	PA
Lake Billy 2	6538-67	2	1	PQ
Lake Harry	6539-5	2 (Q2 only)	1	PA
Marion	6539-4	2 (Q2 only)	1	PA
Maynards	6438-79	N/A	1	PA
MB7	6439-39	2	1	MQ
MB8	6439-40	2	1	MQ
Morphetts	6438-87	N/A	1	PA
Morris Creek	6439-9	N/A	1	PA
Muloorina	6439-20	2 (Q2 only)	1	PA
New Kopperamanna	6640-1	N/A	1	PA
OB 1	6439-27	2	1	MQ
OB 3	6439-26	2	1	MQ
OB 6	6439-24	2	1	MQ
Peachawarinna	6539-1	N/A	1	PA
Peters	6539-8	N/A	1	PQ
S1	6438-97	1	1	MQ
S2	6438-96	2	1	MQ
S3	6538-70	1	1	MQ
S3a	6538-71	1	1	MQ

Bore name	Unit number	Priority		Bore category
		Q1, Q2, Q3	Q4	
S4	6539-16	2	1	MQ
S5	6539-15	2	1	MQ
Sinclair	6639-2	N/A	1	PA
Tarkanina 2	6639-18	1	1	PQ
Tent Hill 2	6538-188	2	1	PQ
Two Mile 2	6538-166	2	1	PQ
WCB 1	6438-80	2	1	MQ
WCB 2	6439-18	2	1	MQ
Well Creek 2	6538-167	2	1	PQ
Wurringina Spring 1	6538-33	2	1	PQ
Yarra Hill	6639-8	N/A	1	PA

Notes:

- Interpretation of category codes is provided in Table 9.1.
- Priority refers to data recovery level if unforeseen circumstance results in missed data: 1 – As soon as possible; 2 – Next scheduled monitoring run. Refer to section 3.3.4 for further details.
- Occasionally a bore may be excluded from the MP due to bore structural failure, a change in operation or other unforeseen circumstance.

Table 9.4: Monitoring for springs around Wellfields A and B

Spring group	Spring code	Spring Flow	Flora Assessment	Invertebrate Assessment
Coward	CBC 001	X	X	X
	CBC 002	X	X	X
	CBC 013	X	X	X
Beatrice	HBS 004	X	X	X
Bopeechee	HBO 004	X	X	X
	HBO 007	X	X	X
	HBO 011	X	X	X
Davenport	WDS 001	X	X	X
	WDS 042 (WDSKE1)	X	X	X
	WDS 052 (WDSKE2)	X	X	X
Dead Boy	HDB 004	X	X	X
	HDB 005	X	X	X
Emerald	LES 001	X	X	X
Fred	^LFE 001	X	X	X
	^LFE 003		X	
	^LFE 004		X	
	^LFE 005		X	
	^LFE 006	X	X	X
	^LFE 007A		X	
Gosse	^LGS 001		X	

Spring group	Spring code	Spring Flow	Flora Assessment	Invertebrate Assessment
	^LGS 002	X	X	X
	^LGS 003		X	
	^LGS 004	X	X	X
	^LGS 005		X	
	^LGS 006		X	
Hermit Hill	HHS 028	X	X	X
	HHS 033		X	X
	HHS 035	X	X	X
	HHS 039		X	X
	HHS 042		X	X
	HHS 072		X	X
	HHS 074		X	X
	HHS 075		X	X
	HHS 077		X	X
	HHS 078		X	X
	HHS 097		X	X
	HHS 101	X	X	X
	HHS 108		X	X
	HHS 111		X	X
	HHS 113		X	X
	HHS 114		X	X
	HHS 116		X	X
	HHS 119		X	X
	HHS 121		X	X
	HHS 122		X	X
	HHS 123		X	X
	HHS 125		X	X
	HHS 125a	x		
	HHS 131		X	X
	HHS 134		X	X
	HHS 135		X	X
	HHS 137	X	X	X
Hermit Hill	HHS 142		X	X
	HHS 144		X	X
	HHS 149		X	X
	HHS 150A		X	X
	HHS 154		X	X
	HHS 155		X	X
	HHS 157		X	X
	HHS 159		X	X
	HHS 160		X	X
	HHS 161		X	X

Spring group	Spring code	Spring Flow	Flora Assessment	Invertebrate Assessment
	HHS 162		X	X
	HHS 165		X	X
	HHS 169		X	X
	HHS 170	X	X	X
	HHS 171		X	X
	HHS 172		X	X
	HHS 173		X	X
	HHS 181		X	X
	HHS 182		X	X
	HHS 186		X	X
	HHS 187		X	X
	HHS 217		X	X
	HHSfenl		X	X
McLachlan	^LMS 001		X	
	^LMS 002		X	
	^LMS 003		X	
	^LMS 004	X	X	X
	*^LMS 004B		X	
North West	HNWlawn		X	X
Old Finnis	HOF 004	X	X	X
	HOF 033	X	X	X
	HOF 058		X	X
	HOF 081	X	X	X
	HOF 094	X	X	X
	HOF 096		X	X
Old Woman	HOW 009	X	X	X
	HOW 015	X	X	X
	HOW 025	X	X	X
Sulphuric	HSS 011	X	X	X
	HSS 012	X	X	X
	HSS 024	X	X	X
Walkarinna	^LWS 007		X	X
	^LWS 009		X	X
	^LWS 012		X	X
	^LWS014		X	X
	^LWS015		X	X
	^LWS016		X	X
Welcome	WWS 001	X	X	X
	WWS 002	X	X	X
	WWS 004	X	X	X
	WWS 013	X	X	X
West Finnis	HWF 001	X		

Spring group	Spring code	Spring Flow	Flora Assessment	Invertebrate Assessment
West Finnis	HWF 002	X	X	X
	HWF 003	X	X	X
	HWF 018		X	X
	HWF 020		X	X
	HWF 021		X	X
	HWF 028		X	X
	HWF 039		X	X
	HWF 043		X	X
	HWF 048	X	X	X

^ GAB springs monitoring as part of the SEB offsets program

Notes:

- Summary of information collected and monitoring frequency are provided in Table 8.1
- All springs are priority 2. Refer to section 2.3.4 for further details.
- Occasionally a spring may be excluded from the MP due to unforeseen circumstance.

Table 9.5: Additional Monitoring of Wellfield A Linked to Wellfield A Extraction

Bore Name	Unit Number	Monitoring Trigger	Monitoring Frequency Once Trigger Reached	Monitoring Parameter
HH2	6338-39	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded	Pressure
GAB7	6338-24	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded	Pressure
GAB8	6338-44	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded	Pressure
GAB10	6338-46	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded	Pressure
GAB11	6338-47	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded	Pressure
GAB19	6338-63	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded	Pressure
Bopeechee HBO013	6338-6	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded and during subsequent recovery period	Flow
Venables	6338-33	Wellfield A average daily extraction >5 ML/d for a month	Increase to monthly whilst trigger exceeded and during subsequent recovery period	Flow

10 APPENDIX E: SUMMARY OF PREDICTED FLOW DECLINE FOR GAB SPRINGS

Predicted spring flow declines are from the environmental impact statements of 1984 and 1997 and updated in 2016 (Golder Associates 14766004-019-M-Rev2). Hydrogeological Zones are based on drawdown levels predicted in Kinhill Stearns (1984) and Kinhill Engineers (1997a).

Table 10.1: Hydrogeological zones

Hydrogeological zone	Spring groups within zone	Range of decline predicted
Coward	Blanche Cup; Coward	<1%
North East	Bopeechee; Dead Boy; Sulphuric; West Finniss	8 – 20%
South East	Davenport; Wangianna; Welcome; Hergott	3 – 16.5%
South West	Hermit Hill; Old Finniss; Old Woman	<1 – <3%
Wellfield A	Beatrice; Priscilla; Venables; Fred	60 – 100%
Western Lake Eyre South	Emerald; McLachlan; Gosse	3 – 17%

Notes:

The hydrogeological zone allocated to some spring groups does not follow predictions in Kinhill Stearns (1984) precisely as the hydrogeological relationships have been revised. Further revisions may be undertaken, as relationships are better understood.

11 APPENDIX F: SUMMARY OF PREDICTED DRAWDOWN TO 2036 AT PASTORAL BORES IN THE WELLFIELD B REGION

Predictions follow Kinhill Engineers (1997a) – updated 2016 (Golder Associates 14766004-019-M-Rev2).

Table 11.1: Predicted drawdown

Bore name	Unit Number	Predicted drawdown (kPa)	Bore name	Unit Number	Predicted drawdown (kPa)
Callanna	6438-95	8	Lake Harry	6539-5	149
Cannuwaukaninna	6640-4	55	Marion	6539-4	147
Chapalanna 2	6639-19	27	Maynards	6438-79	14
Charles Angus	6438-1	27	Morphetts	6438-87	10
Clayton	6539-2	107	Morris Creek	6439-9	41
Clayton 2	6539-9	107	Muloorina	6439-20	159
Clayton Dam 2	6639-12	15	New Kopperamanna	6640-1	48
Cooranna	6438-4	42	Peachawarinna	6539-1	131
Cooryanna 2	6639-16	41	Peters	6539-8	118
Dulkaninna 2	6539-14	73	Tarkanina 2	6639-18	51
Frome Creek 2	6538-210	11	Yarra Hill	6639-8	25
Jackboot	6339-6	50			

Notes:

Predicted drawdown for Tarkanina 2 is listed in the EIS (Kinhill Engineers 1997a) as 63 kPa. This is an error, the value having been confused with that predicted for Tarkanina 1 located further west and within the **designated area** boundary. Tarkanina 2 serves as a proxy compliance bore and drawdown is expected to remain less than 6m at around 51 kPa.