Wheatstone Project

BIRDRONG AQUIFER WATER SOURCE FATAL FLAW ANALYSIS (TWO ALTERNATIVES)
Onslow Water Infrastructure Upgrade Project

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October 2012

BIRDRONG AQUIFER WATER SOURCE FATAL FLAW ANALYSIS (TWO ALTERNATIVES)

Wheatstone Social Infrastructure Onslow Water Infrastructure Upgrade Project

Submitted to:
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REPORT

Report Number. 127646019-004-R-Rev1

Distribution:

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Golder Associates

Executive Summary

Chevron Australia Pty Ltd is in the process of identifying any fatal flaws associated with the abstraction of groundwater from the Birdrong Aquifer for the purposes of providing potable water supplies to the town of Onslow. As part of this investigation, Golder Associates Pty Ltd has addressed 2 objectives (Objectives 1 and 3) outlined in CVX CTR No.002 as follows:

Objective 1: Use new data to inform the existing conceptual groundwater model (where new data will assist) to determine impacts and sustainability of a Birdrong Aquifer solution for an 80 year abstraction period to develop an understanding of any fatal flaws or constraints associated with the Birdrong Aquifer for the Onslow Township water supply. Sustainability to be assessed for the scenarios' tabulated below:

Table 1: Pumping Scenarios for 80 Year Abstraction Period

Scenario	Scenario Description
1	Pumping 8.3 ML/day* from MDW4 only
2	Pumping 1.5 ML/day* from MDW4 and 6.8 ML/day from CVX2

*Raw water extraction rates based on BHPB requiring an estimated 1.5ML/day of raw water from MDW4 to support the operation of the BHPB Macedon DomGas plant and 6.8 ML/day of raw water is required to support the production of 4 ML/day of potable water for Onslow (ultimate capacity of the desalination plant).

Objective 3: Document fatal flaws, if any, associated with water quality from the Birdrong Aquifer and its proposed use in desalination to potable water that would meet the quality requirements of the WA Department of Health.

A three dimensional numerical model developed in the FEFLOW finite element code was to assess the two 80 year pumping scenarios, with the following results:

Scenario	Scenario Description	Drawdown After 80 Years
1	Pumping 8.3 ML/day from MDW4 only	107 m
2	Pumping 1.5 ML/day from MDW4 and 6.8 ML/day from CVX2	MDW4 25m, CVX2 86m

The two modelled scenarios indicated:

- The Birdrong Aquifer remained saturated for both modelled scenarios;
- The Birdrong Aquifer remained artesian, but not flowing artesian, for both modelled scenarios; and
- Pumps would need to be installed in the wells to sustain flow at the modelled abstraction rates.

It is important to note that the numerical modelling does not take into account hydraulic efficiency considerations of pumping the wells at the modelled abstraction rate, and that the numerical model is a simplification of a complex groundwater environment. The extent to which drawdown/depressurisation and groundwater quality is affected by the prolonged pumping, leakage from above and below, the presence of aquifer structures, boundaries and inhomogeneities etc., is not known.

Monitoring data from MDW4 does not provide much additional insight into the groundwater flow system, except that heads appear to recover fully if the well is shut-in for what is assumed to be a number of days. Better monitoring data would confirm this.

In the context of Objective 3 of the current study, no fatal flaws associated with water quality from the Birdrong Aquifer have been identified, and potable water is understood to be operationally produced from raw water from MDW4.

Furthermore, based upon the information currently available and numerical modelling undertaken as part of the current study to date, there appears to be no aquifer sustainability or water quality issues which would impede upon the issuing of a 5C Licence to abstract groundwater from the Birdrong Aquifer at the rates modelled herein.

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TABLES

FIGURES

1.0 INTRODUCTION

Chevron Australia Pty Ltd (Chevron) is in the process of identifying any fatal flaws associated with the abstraction of groundwater from the Birdrong Aquifer for the purposes of providing potable water supplies to the town of Onslow (Figure 1). As part of this investigation, Chevron has asked Golder Associates Pty Ltd (Golder) to address 2 objectives (Objectives 1 and 3) outlined in CVX CTR No.:002 as follows:

Objective 1: Use new data to inform the existing conceptual groundwater model (where new data will assist) to determine impacts and sustainability of a Birdrong Aquifer solution for an 80 year abstraction period to develop an understanding of any fatal flaws or constraints associated with the Birdrong Aquifer for the Onslow Township water supply. Sustainability to be assessed for the two scenarios' tabulated below:

Scenario No.	Scenario Description
1	Pumping 8.3ML/day* from MDW4 well only
2	Pumping 1.5ML/day* from MDW4 and 6.8ML/day* from a new well (CVX2) in a location that does not impact the sustainability of drawing 1.5ML/day from MDW4

*Raw water extraction rates based on BHPB requiring an estimated 1.5ML/day of raw water from MDW4 to support the operation of the BHPB Macedon DomGas plant and 6.8 ML/day of raw water is required to support the production of 4 ML/day of potable water for Onslow (ultimate capacity of the desalination plant).

Objective 3: Document fatal flaws, if any, associated with water quality from the Birdrong Aquifer and its proposed use in desalination to potable water that would meet the quality requirements of the WA Department of Health.

Golder were also asked to assess whether the recently collected groundwater monitoring data from well MDW4 can be used to improve the existing groundwater conceptual model.

The aim of this report is to:

- Document the analysis of the existing groundwater monitoring data.
- Use 3D groundwater modelling to examine the long term sustainability of abstracting groundwater from MDW4 and possible new wells (Scenarios 1 and 2).
- Document identified fatal flaws associated with water quality from the Birdrong Aquifer (Objective 3).

2.0 BACKGROUND

Golder has previously carried out the following groundwater assessments within the Birdrong Aquifer:

- Golder 2010a: Selection of suitable well locations based on interpretation of geophysical data.
- Golder 2011: H2 Level Hydrogeological assessment of the Macedon Deep Well (MDW4). In this report, the well construction details and the results of hydraulic testing are documented. Well MDW4 is screened within the Birdrong Aquifer.
- Golder 2012a: 2D groundwater modelling to assess the effects on the Birdrong Aquifer, of groundwater abstraction from well MDW4. The report produced from this assessment was used as supporting documentation in an application to the Department of Water (DoW) to temporary increase the allocation for abstraction from MDW4.
- Golder 2012b: Birdrong Aquifer Assessment - Seismic Data Availability.
- Golder 2012c: 3D groundwater modelling to assess the effects of groundwater abstraction from well MDW4 and two other proposed wells (CVX2 and CVX3). The maximum period of groundwater abstraction assessed was 20 years.

3.0 REVIEW OF GROUNDWATER MONITORING DATA

The manual field monitoring data collected by site personnel and made available to Golder is presented in Table 2. An analysis of the well head pressures measured manually in MDW4 (Table 2) and the continuous wellhead pressure measured with an automatic data logger (Figure 2) suggests that the manual measurements were made for both flowing and shut-in well conditions. Between 6 June and 2 July 2012, the well head pressures under flowing conditions were approximately 30 KPa (Figure 2). For the period of continuous water pressure monitoring, the highest well head pressure of approximately 295 KPa was recorded when the well was shut-in between 22 June and 24 June 2012. A higher wellhead pressure was recorded on 27 May 2012 (Table 2), indicating significant pressure recovery to pre abstraction heads, presumably after a few days of shut-in.

Table 2: Manual Field Monitoring Data, MDW4

Date	Well Head Pressure (KPa)	pH	Electrical Conductivity (uS/cm)	Total Dissolved Solids (ppt) (1)	Temperature (°C)
15/07/2011	100	#N/A	-	#N/A	#N/A
10/08/2011	#N/A	7.5	20430	11.9	#N/A
9/09/2011	#N/A	7.08	-	13.3	#N/A
28/09/2011	100	7.66	22650	13.7	31.4
6/10/2011	100	7.08	28150	13.4	46.9
4/11/2011	175	7.22	22200	13.6	44.1
4/12/2011	105	6.91	21.6	14.6	44.2
22/12/2011	260	7.06	21.14	12.9	43.0
4/01/2012	220	6.8	21.19	12.9	44.3
6/02/2012	110	6.89	22.3	13.6	48.6
28/02/2012	70	7.86	20.51	12.36	30.7
30/03/2012	#N/A	#N/A	-	#N/A	#N/A
8/04/2012	75	6.9	18.5	11.1	41.2
15/04/2012	80	6.9	21.38	13.01	37.6
22/04/2012	#N/A	#N/A	-	#N/A	#N/A
29/04/2012	90	6.8	20.6	12.5	46.9
6/05/2012	40	6.9	20.0	7.8	43.3
13/05/2012	80	6.8	13.4	7.9	45.4
20/05/2012	70	6.93	18.9	12.1	49.0
27/05/2012	390	#N/A	-	#N/A	#N/A
3/06/2012	80	6.8	21.12	12.88	45.9
10/06/2012	70	6.70	21.2	12.9	45.3
17/06/2012	270	6.77	20.7	12.67	47.4
24/06/2012	250	6.79	21.0	12.75	47.9
1/07/2012	170	6.9	20.29	12.77	44.3

Note: (1) ppt = parts per thousand. **BOLD** data likely to represent mS/cm.

Historical flow data indicates that instantaneous flow rates may be as high as approximately 55 L/s, although more typical flow rates range from approximately 30 to 5 L/s. The data is of such quality that the higher indicated flow rates (about 50 L/s) may not be reliable.

4.0 LONG TERM DRAWDOWN PROJECTIONS

4.1 Introduction

A 3D groundwater model, developed in FEFELOW, was used to calculate the likely long-term groundwater drawdown that would result as a result of abstraction from the Birdrong Aquifer. The drawdown projections were assessed for an 80 year abstraction period for two scenarios. The two modelled scenarios are presented in Table 3.

Table 3: Pumping Scenarios for 80 Year Abstraction Period

Scenario	Scenario Description
1	Pumping 8.3 ML/day from MDW4 only
2	Pumping 1.5 ML/day from MDW4 and 6.8 ML/day from CVX2

4.2 Conceptual Groundwater Model

The information obtained from the analysis of the new groundwater monitoring data has not raised any issues that could change our understanding of the groundwater flow system. Therefore, the conceptual model described in the previous report (Golder 2012c) was considered appropriate for this analysis.

A summary of the hydraulic parameter values assigned to the model is presented in Table 4. The parameter values are similar to those assigned in the previous groundwater model (Golder 2012b). The conceptual groundwater model developed for assessing the Birdrong Aquifer consists of the following elements.

- The Birdrong Aquifer was assigned a thickness of 30 m to include overlying and underlying aquifers in hydraulic connection with the Birdrong sandstone. A hydraulic conductivity of 3.0×10^{-5} m/s was assigned to the Birdrong Aquifer. The specific yield and specific storage applied to this layer in the model were 35% and 1×10^{-5} ^{1}/m respectively.
- The sediments overlying the Birdrong Aquifer were grouped into a single hydrostratigraphic unit with a hydraulic conductivity of 1×10^{-9} m/s. The specific yield and specific storage applied to this layer in the model were 10% and 1×10^{-5} ^{1}/m respectively.
- The geological formations occurring below the Birdrong Sandstone were not included in the groundwater model. Setting an impermeable boundary at the base of the Birdrong Aquifer was done to prevent upward groundwater leakage into the Birdrong Aquifer during pumping. This modelling approach was considered to be conservative.
- For the purposes of this assessment it has been assumed that the offshore extent of the Birdrong Aquifer is up to 120 km to the west of the site. It has also been assumed that the Birdrong continues with the same dip and thickness to the model boundary.
- Information on the permeability characteristics of the faults is poorly understood. For the purposes of this assessment, it has been assumed that the faults do not affect groundwater flow within the Birdrong Aquifer.
- A groundwater recharge of 1×10^{-5} m/day was applied to the outcrop of the Birdrong Aquifer to the east of Onslow. This recharge rate was obtained during the calibration of the steady state groundwater model (Golder 2012b).
- No groundwater recharge was applied over the top of overlying layer.

Table 4: Hydraulic Parameter Values Assigned to Groundwater Model

Parameter	Birdrong Aquifer	Overlying Layer
Hydraulic conductivity (m/s) (1)	3.0×10^{-5}	1×10^{-9}
Specific yield	0.35	0.10
Specific storage (1/m)	1×10^{-5}	1×10^{-5}
Groundwater recharge rate (m/d)	1×10^{-5}	-

4.3 Numerical Groundwater Model

The 3D numerical model described in the previous report (Golder 2012b) was used in this analysis. The only modification to the previous model is that the mesh in the area around the pumping wells was refined to improve the numerical solution (Figure 3). A typical E-W cross section through the modelled area is presented in Figure 4.

The following model boundaries were assigned to the model:

- The nodes along the offshore western boundary were assigned seepage face boundary conditions. A seepage face boundary is a special type of a hydraulic head boundary. Groundwater flows out of the model when calculated head is above the topographic elevation of the seepage boundary node. However, groundwater inflow into the model cannot occur through seepage boundary nodes.
- Zero hydraulic head (h=0 m) boundary conditions were assigned to the top of Layer 1 in the offshore region to represent the sea.
- A constant groundwater recharge rate of 1×10^{-5} m/day was applied over the outcrop area of the Birdrong Aquifer.
- No flow conditions were assigned to the following model boundaries:
- Base of model, represented by the base of the Birdrong Aquifer.
- East of the model along the contact with the Precambrian basement.
- Southern limit of the model. This boundary is very distant from the area of interest and the effects of the pumping are unlikely to propagate to this boundary.
- Northern limit of the model. This boundary is very distant from the area of interest and the effects of the pumping are unlikely to propagate to this boundary.

4.4 Results

4.4.1 Model Scenario 1 - Pumping 8.3 ML/day from MDW4 only

The projected drawdown contours at the end of 80 years of pumping are presented in Figure 5.
The maximum projected drawdown at well MDW4 is approximately 107 m. This means that the projected hydraulic head at well MDW4, at the end of the 80 year abstraction is approximately -80 mAHD. The top of the Birdrong Aquifer is at an elevation of approximately -362 m AHD. Therefore, the Birdrong Aquifer is likely to remain fully saturated throughout the 80 year pumping period.

4.4.2 Model Scenario 2 - 1.5 ML/day from MDW4 and 6.8 ML/day from CVX2

The projected drawdown contours at the end of the 80 year abstraction period are presented in Figure 6.
The maximum projected drawdown at well MDW4 is approximately 25 m. The maximum projected drawdown at proposed well CVX2 is approximately 86 m. Artesian aquifer conditions are likely to be retained during the pumping period.

4.4.3 Well Interference Effects

A comparison of the projected drawdown at well MDW4 for an 80 year abstraction period was done for the following scenarios:

- Pumping from well MDW4 only at 1.5 ML/day for 80 years.
- Pumping from well MWD4 at 1.5 ML/day; pumping from the proposed CVX2 well at 6.8 ML/day. This option is referred to as Scenario 2 in Table 3.

The hydraulic head at well MDW4 at the end of the 80 year abstraction period for the scenario with one well only is projected to be approximately 11 m. The hydraulic heads at well MWD4 for Scenario 2 is 2 m. The abstraction from well CVX2 would result in an additional drawdown at MDW4 of approximately 9 m.

4.4.4 Discussion on Sustainability

The overall objective of the modelling was to assess the sustainability of abstraction for the various pumping scenarios. In all modelled cases, the Birdrong Aquifer remained fully saturated. Arguably this indicates that the abstraction scenarios are all sustainable to the extent that they do not dewater the aquifer. Apart from MDW4 itself, there are no other known users of the Birdrong Aquifer in this northern part of the Carnarvon Artesian Basin, so there are no impacts on other beneficial users.

In all scenarios, the aquifer will be sufficiently depressurised so that flowing artesian conditions will cease. Pumps will therefore need to be installed in all wells (including MDW4) to maintain desired abstraction rates for 80 years. The additional drawdown experienced at MDW4 due to pumping from the other well simply equates to more pumping effort to overcome the additional pumping heads required.

It is important to note that the numerical modelling does not take into account hydraulic efficiency considerations of pumping the wells at the modelled abstraction rate, and that the numerical model is a simplification of a complex groundwater environment. The extent to which drawdown/depressurisation and groundwater quality is affected by the prolonged pumping, leakage from above and below, the presence of aquifer structures, boundaries and inhomogeneities etc., is not known.

5.0 WATER QUALITY

5.1 Fatal Flaws - Objective 3

Golder understands that potable water is being produced from raw water sourced from MDW4. As such, we are not aware of any fatal flaws associated raw water from the Birdrong Aquifer being used to produce potable water after appropriate treatment.

5.2 Items for Further Consideration

At this stage, the key water quality operational considerations associated with raw groundwater sourced from the Birdrong Aquifer, and indicated from the current amount of available chemistry data are as follows:

- The presence of radionuclides - water from the Macedon Deep Well (MDW4) is known to contain U-238, Ra-228 and Rn-222. The Birdrong Formation is a classic setting for sandstone hosted roll-front uranium mineralisation, and in the 1990's, WMC drilled the formation on Peedamulla Station, in search of uranium. Additionally, Energia Minerals Limited have intersected uranium mineralisation (3m @ 303 ppm U3O8) in the Formation, approximately 35 km south southeast of Onslow (Energia Minerals Limited, www.energiaminerals.com).
- Dissolved gas - a significant amount of gas (mostly methane) comes out of solution at MDW4,
- Dissolved iron - a significant amount of iron comes out of solution at the Macedon deep well (MDW4)

Water treatment processes designed to bring the Birdrong Aquifer raw water up to drinking water quality would have to consider the site specific raw groundwater quality obtained from the aquifer, at the individual

locations of any new wells. RO (Reverse Osmosis) treatment can treat a wide variety of radionuclides however the full chemistry of the groundwater must be understood, including the products of re-equilibration to atmospheric conditions to ensure, for example, that radionuclide complexing with other components in the water, do not block membranes. This is a matter of evaluation for each treatment process and plant.

Advice from the Department of Health indicates that all drinking water service providers in WA must comply with the Australian Drinking Water Guidelines. The effectiveness of any treatment process must therefore take into account the full suite of analytes that must be screened to comply with Australian Drinking Water Guidelines, but also the efficiencies of individual water treatment process for individual chemical constituents of the raw water.

6.0 SUMMARY AND CONCLUSIONS

Monitoring data from MDW4 does not provide much additional insight into the groundwater flow system, except that heads appear to recover fully if the well is shut-in for what is assumed to be a number of days. Better monitoring data would confirm this.

In the context of Objective 1, the key findings from the modelling are as follows:

- If well MDW4 is pumped continuously at a rate of 8.3 ML/day for an 80 year abstraction period, the groundwater drawdown at the pumping well is projected to be approximately 107 m. The Birdrong Aquifer is expected to remain fully saturated and artesian (but not flowing artesian) for the duration of the pumping.
- If MDW4 and the proposed well at CVX2 are pumped at rates of 1.5 ML/day and 6.8 ML/day respectively, the projected drawdown at well MDW4 is approximately 25 m. The projected drawdown at CVX2, at the end of the 80 year abstraction is approximately 83 m. The Birdrong Aquifer is expected to remain fully saturated and artesian (but not flowing artesian) for the duration of the pumping.
- The well interference analysis (Section 4.4.5) indicates that, for an 80 year abstraction period, additional drawdown at MDW4 of approximately 9 m would occur at CVX2 due to simultaneous abstraction.

Summarising, the two modelled scenarios indicated:

- The Birdrong Aquifer remained saturated for both modelled scenarios;
- The Birdrong Aquifer remained artesian, but not flowing artesian, for both modelled scenarios; and
- Pumps would need to be installed in the well to sustain flow at the modelled abstraction rates.

In the context of Objective 3 of the current study, no fatal flaws associated with water quality from the Birdrong Aquifer have been identified, and potable water is understood to be operationally produced from raw water from MDW4.

Furthermore, based upon the information currently available and numerical modelling undertaken as part of the current study to date, there appears to be no aquifer sustainability or water quality issues which would impede upon the issuing of a 5C Licence to abstract groundwater from the Birdrong Aquifer at the rates modelled herein.

7.0 REFERENCES

Golder 2010a: Macedon Water Well Geologic Study, Seismic Interpretation and Well Log Analysis Report. Report No. 1078208343_R001_Rev0.0 dated 22 October 2010. Report prepared for BHP Billiton Petroleum Pty Ltd by Golder Associates (NZ) Limited.

Golder 2011: Macedon Deep Well, H2 Level Hydrogeological Assessment. Report No. 117646002-003-R-Rev1. Report prepared for BHP Billiton Petroleum Pty Ltd by Golder Associates Pty Ltd.

Golder 2012a: Macedon Deep Well, Supplementary H2 Level Assessment Report. Supplementary H2 Level Assessment Report. Report No. 117642115-022-R-Rev0. Report prepared for BHP Billiton Petroleum Pty Ltd by Golder Associates Pty Ltd.

Golder 2012b: Birdrong Aquifer Assessment - Seismic Data Availability. Technical Memorandum 127646019-002-M-Rev0, 6 July 2012.

Golder 2012c: Birdrong Aquifer Assessment, Groundwater Modelling of the Birdrong Aquifer. Report No. 127646019-001-R-Rev0. Report prepared for Chevron Australia Pty Ltd by Golder Associates Pty Ltd, July 2012.

Golder 2012d: Onslow Water Infrastructure Upgrade Project - Birdrong Aquifer Water Source Fatal Flaw Analysis - CVX CTR No.002, Contract C737965. Golder Technical Memorandum 127646019-003-M-Rev0, dated 31 August 2012.

Report Signature Page

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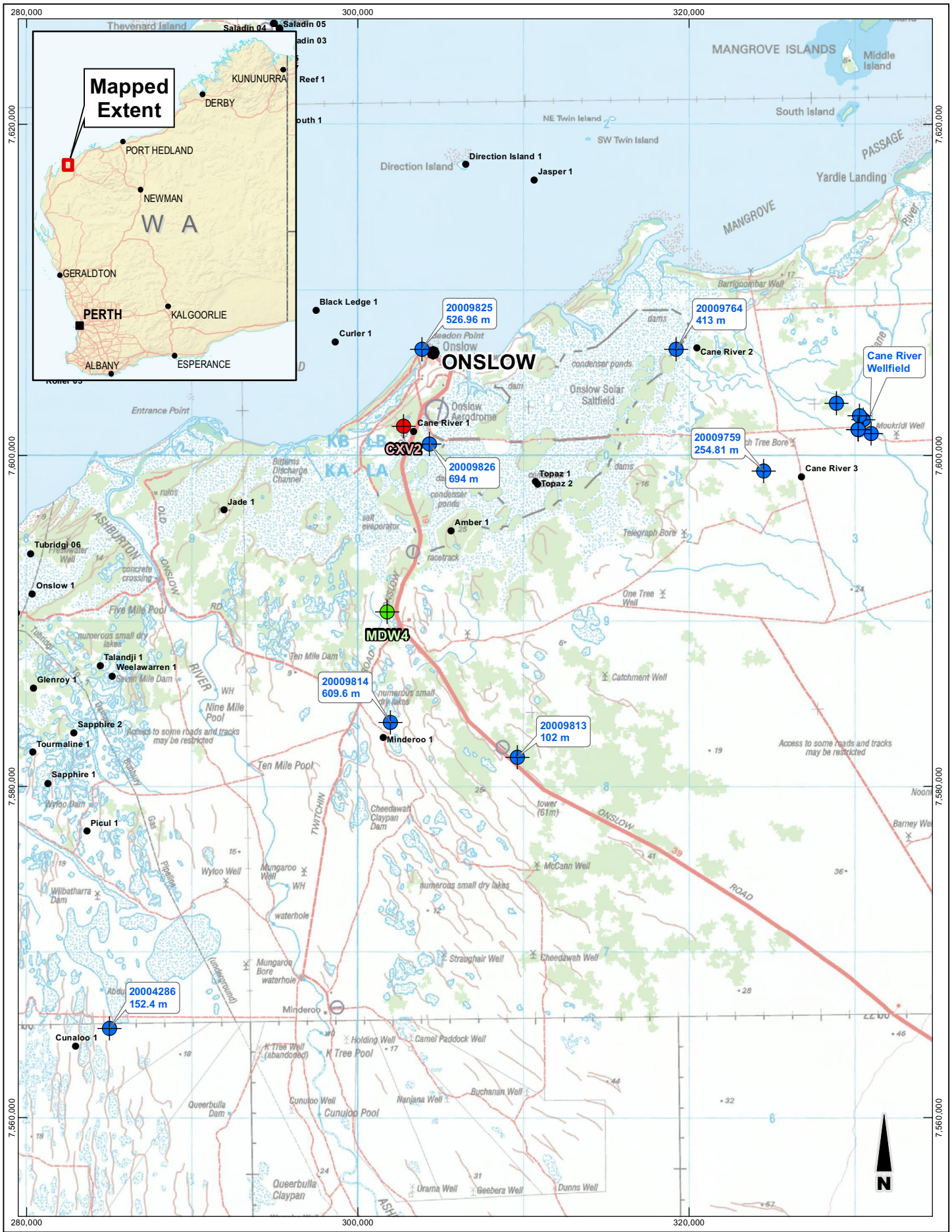

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DATE	19 Nov 2012
COMPILED	GGW
APPROVED	DMT

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NOTES
Coordinate System: GDA 1994 MGA Zone 50

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Topgraphical data sourced from StreetPro Display 2009.
WIN Sites sourced from DoW 2012.

LEGEND
- Macedon Deep Well
- Proposed Well Location
- WIN Site
- Petroleum Well

Birdrong Aquifer
Fatal Flaw Analysis

SITE LOCATION AND WELL LOCATIONS

FIGURE 1

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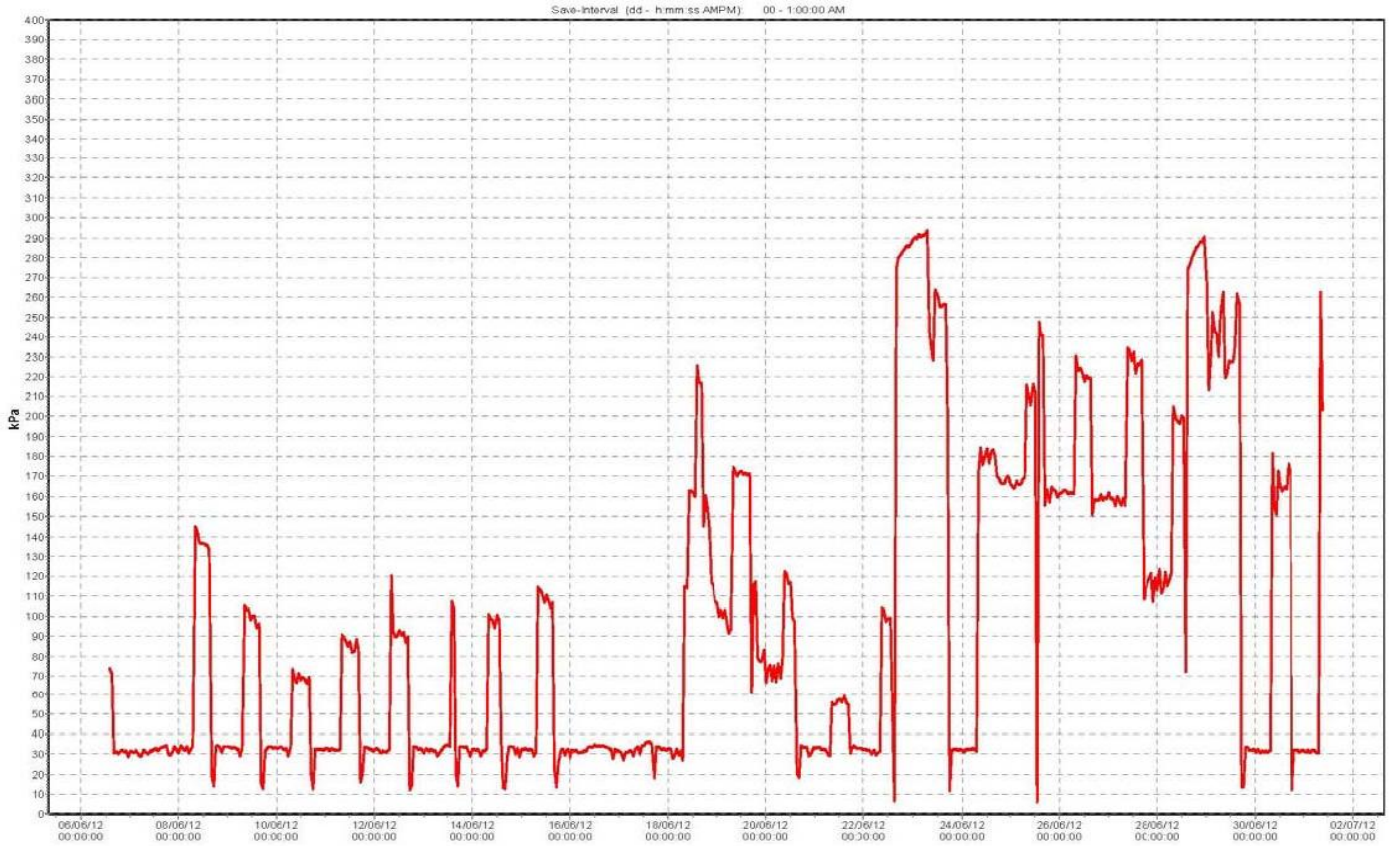

NOTE: Data provided to Golder Associates in PDF format

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DRAWN: DMT	DATE: 6/09/2012		TITLE: **WELLHEAD PRESSURES LOGGER DATA**
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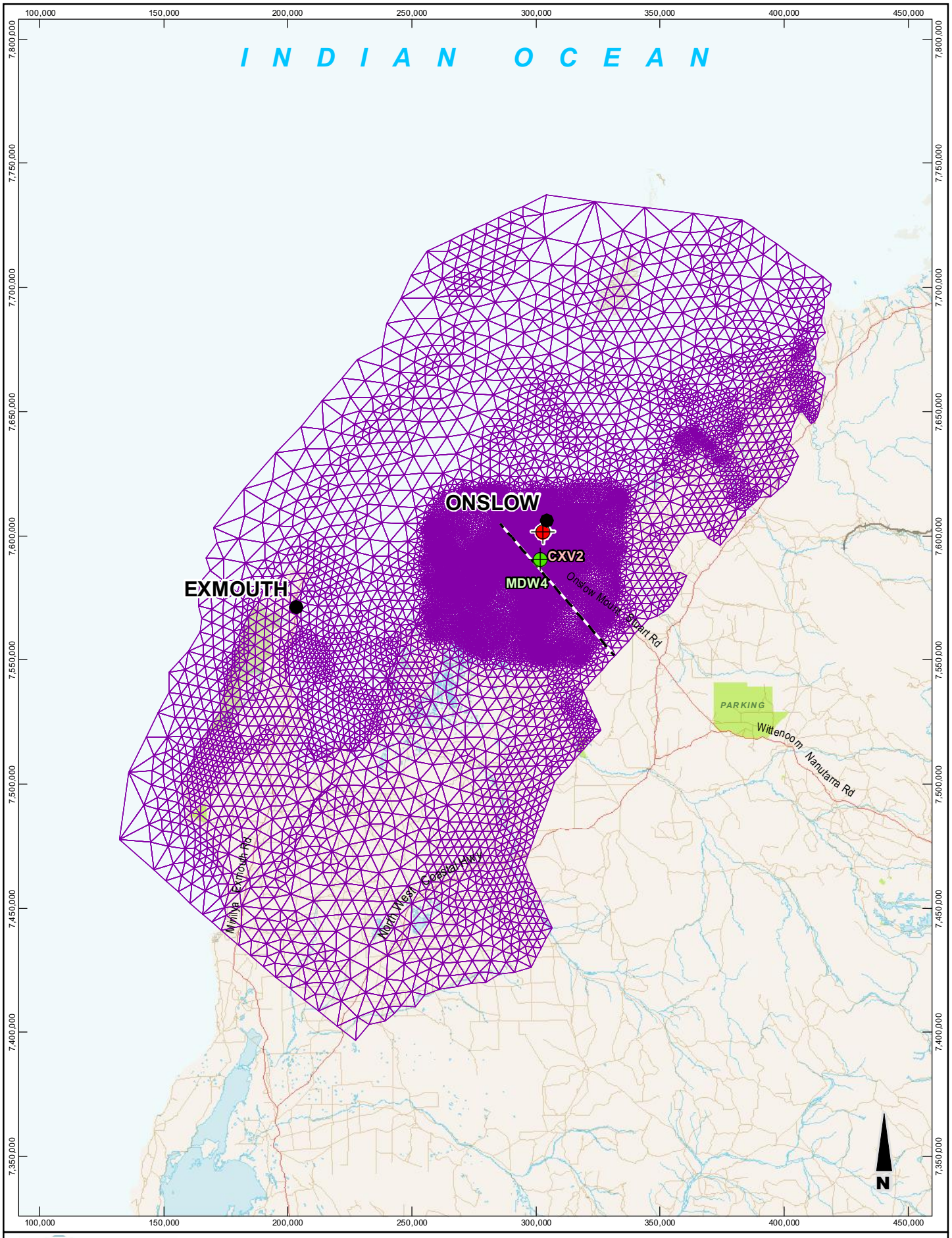

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LEGEND
- Proposed Well Location
- Macedon Deep Well
- Cross Section
- Model Mesh

Birdrong Aquifer Fatal Flaw Analysis

MODEL MESH STRUCTURE

FIGURE 3

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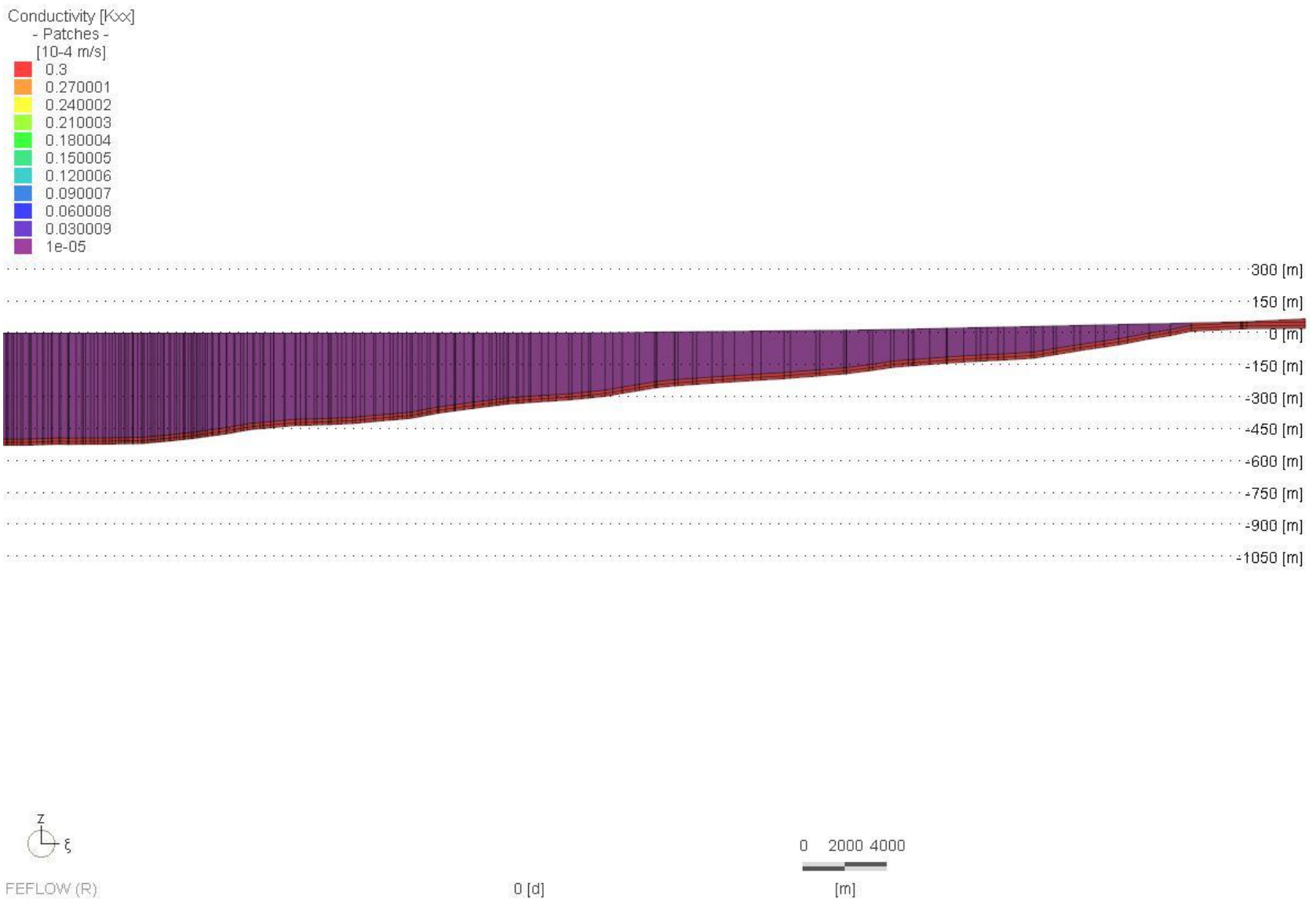

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Birdrong Aquifer
Fatal Flaw Analysis

MODEL CROSS SECTION THROUGH SITE

FIGURE 4

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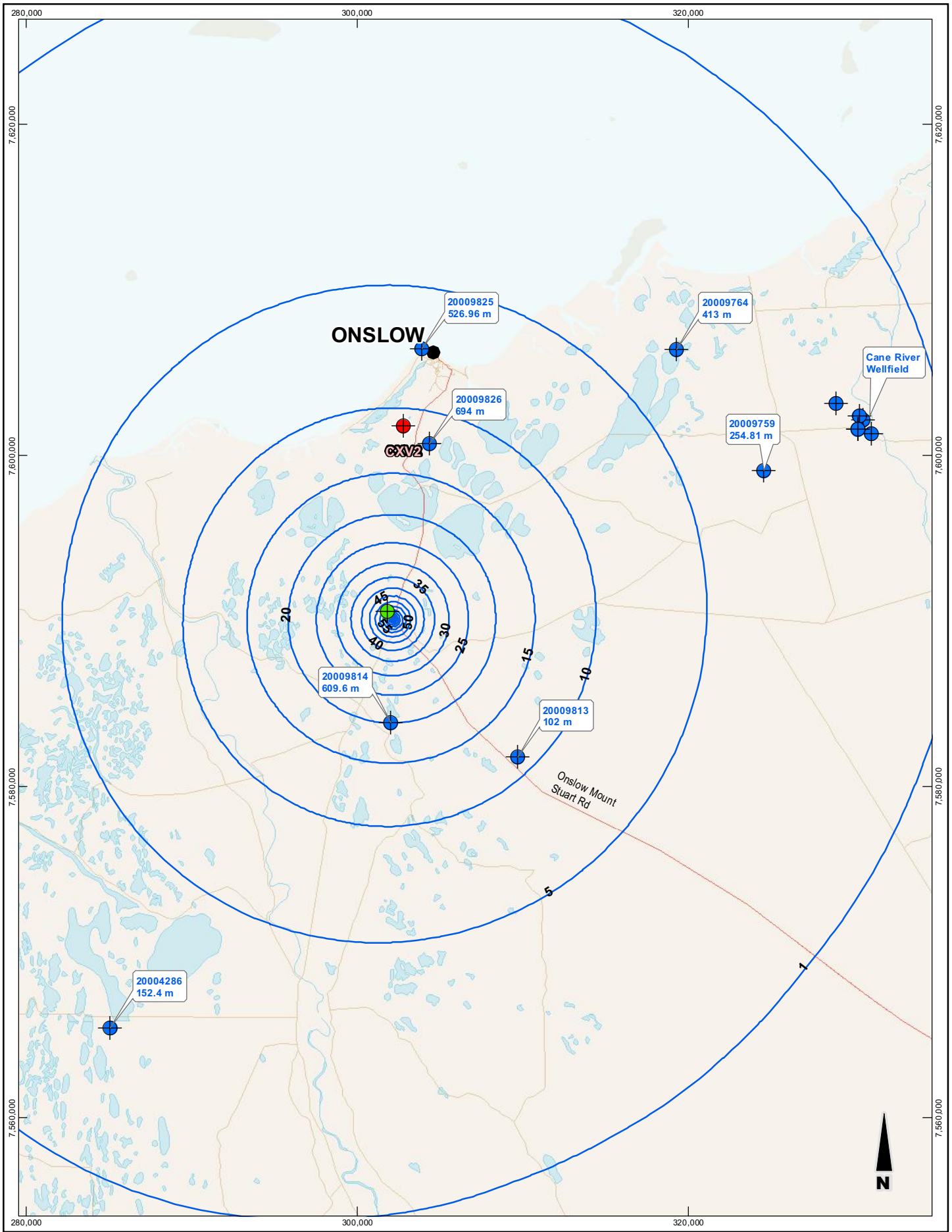

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LEGEND
- Macedon Deep Well
- WIN Site
- Proposed Well Location
- Drawdown Contour (m)

Birdrong Aquifer
Fatal Flaw Analysis

SCENARIO 1

FIGURE 5

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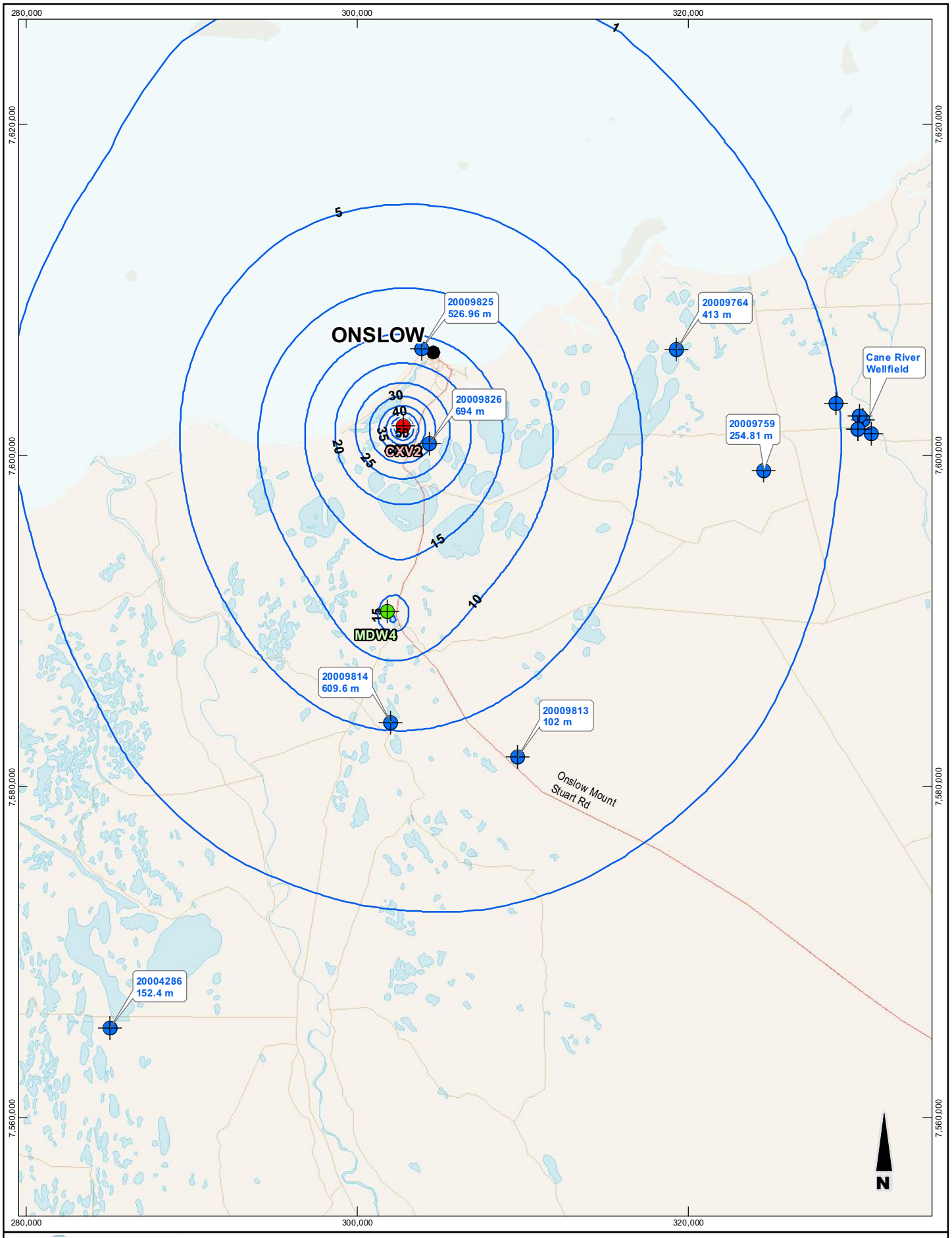

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km

SCALE (at A4) 1:300,000

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LEGEND
- Macedon Deep Well
- WIN Site
- Proposed Well Location
- Drawdown Contour (m)

Birdrong Aquifer
Fatal Flaw Analysis

SCENARIO 2

FIGURE 6

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