INTERA Geosciences Pty Ltd
580 Hay Street, Suite 166
Perth, WA 6000
+61 0410 283 909
INTERA.com

16 May 2024

Ashley Fertch
Director
Australasian Environmental Solutions
Perth, WA 6000

RE: Response to comments on the 3 October 2023 technical memorandum titled "Modelling of drawdown impacts from proposed rig supply bores in the Bennett Resources Valhalla Gas Development Project"

Dear Mr. Fertch,

In October of 2023 INTERA Geosciences Pty Ltd (INTERA) submitted the above-referenced memo (the "original memo") to Australasian Environmental Solutions (AES). In March of 2024 INTERA received a set of comments generated by an independent review of the memo by an external reviewer. The specific comments received are as follows:

1. *The model has several parameter assumptions and many limitations.*
    a. *Can the parameters and assumptions be clearly stated. Specifically, can a sensitivity analysis be conducted for these parameters [aquifer/aquitard thickness, hydraulic conductivity, aquifer thickness, storage] (i.e. increase/ decrease the values and run multiple options through the model to understand the impact of these assumptions)*
    b. *Can a number of extraction rates be studied to understand impacts of varied extraction rates.*
    c. *Can the limitations be described and justified why they are suitable for the purpose of this analysis.*
    d. *Justify why only single model layers are suitable (rather than multiple layers) and validate this against the vertical stratigraphy.*
2. *AES has been informed that MODFLOW 2005 may be outdated and have been informed other software is available (MODFLOW version includes MODFLOW-6, MODFLOW-USG, MODFLOW-SURFACT). Is it possible to provide a justification as to the software suitability for the scope?*

The attached memo titled "Revised modelling of drawdown impacts from proposed rig supply bores in the Bennett Resources Valhalla Gas Development Project" (the "revised memo") contains an updated modeling evaluation prepared in response to the review comments. This letter summarizes the updated modeling and analysis done to address those comments.

Model Software Update

Comment 2 noted that the model was prepared using MODFLOW-2005 rather than one of the later editions of the modeling software. MODFLOW-2005 was chosen because it is an appropriate model for the scope of the problem (i.e., simulating drawdowns in an aquifer for a specific pumping scenario for both confined and unconfined conditions). The subsequent versions of the modeling software, including the latest MODFLOW version (MODFLOW 6), include the same basic modeling techniques used to simulate drawdown and contain significant modeling capabilities that are not specifically applicable to the problem addressed in the memo, therefore, the use of MODFLOW 6 or any of the other software packages listed were not considered.

In response to this comment, the model developed for the original memo was ported to the MODFLOW 6 software environment and the original models simulations were performed. Updated drawdown maps and a discussion of the results are presented in Section 5 of the revised memo. In summary, all model results are essentially equivalent to the previous results. For the Liveringa simulation the modeled drawdowns at all existing bores were less than <0.01 m and the production wells were capable of producing the required amounts with drawdowns that are much less than the available saturated thickness. For the Grant/Poole simulation, the modeled drawdowns at all existing bores were less than 0.4 m and the production wells experienced drawdowns of less than a meter.

Model Input Parameter Justification

Comment 1 discusses input parameter assumptions and requests justifications for the assumptions and parameters used in the model. The requested discussions are included in the revised memo in a new section called **Section 6.0 Modeling Limitations and Sensitivity Analysis**. This section includes a discussion of model limitations and the appropriateness of using single layer models rather than multi-layer models.

Model Sensitivity Analysis

Comment 1 also includes a request for a model sensitivity analysis to evaluate model sensitivity to reasonable ranges of input parameters as well as various extraction rates. A sensitivity analysis was performed using the revised MODFLOW 6 version of the models. The sensitivity analysis uses a variety of extraction rates that range from 50% to 300% of the expected extraction rates, with the overall pumping time (182 days) held constant. For the Liveringa unconfined model the sensitivity to variations in hydraulic conductivity and specific yield were investigated. Hydraulic conductivity values were varied over 5 orders of magnitude (0.00001 to 0.1 m/d) to match the reported range of values presented in the original memo. The results from the original simulations were included in the analysis for comparison. The approach and results are also presented in Section 6 of the revised memo.

Summary of Results for Revised Memo

Model simulations with the updated model software successfully reproduced the results from the original memo. The sensitivity analysis indicates that some of the unconfined aquifer simulations with the most restrictive input parameters indicate that the Liveringa formation may not be able to sustain 100% of the required pumping rates; however, these simulations assume a conservative pumping approach (i.e., all wells pumping at the same time and at maximum rates rather than pumping staggered throughout the gas production well development period) so these simulations are not interpreted to indicate that the proposed well production from the shallow unconfined system is not viable. All simulations for the confined Grant/Poole system indicate that the aquifer is capable of supplying the required volume of water, and most simulations other than the lowest ranges of T and S with pumping rates greater than 100% of the required volume indicate minimal impact to existing bores.

If you have any questions or require further information, please contact me at muliana@intera.com or 0450 971 620.

Sincerely,

INTERA Incorporated

Matthew Uliana, Ph.D., P.G.
Principal Hydrogeologist

Enclosure

INTERA Geosciences Pty Ltd
300 Murray Street Level 2 East
Perth, WA 6000 Australia

TECHNICAL MEMORANDUM

To: Ashley Fertch
Marnie Leybourne
Australasian Environmental Solutions

From: Matthew Uliana, PhD, PG
Principal Hydrogeologist

Date: 16 May 2024

Re: Revised modelling of drawdown impacts from proposed rig supply bores in the Bennett Resources Valhalla Gas Development Project

1.0 Introduction

As requested, INTERA has prepared the following groundwater model-based evaluation of potential aquifer drawdowns and well interference at the proposed Valhalla site near Fitzroy Crossing, WA. It is our understanding that 20 hydrocarbon exploration wells across 10 well sites are proposed (**Figure 1-1**) with two water production bores installed at each wellsite for rig supply. The overall extent of the development is indicated on Figure 1-1 as the Development Envelope (also referred to in this report as the "project site"). Bennett Resources is proposing to undertake an unconventional exploration drilling and hydraulic fracture stimulation program within the study area targeting hydrocarbons in the Laurel Formation at depths ranging from 2,000 meters (m) to 4,000 m below ground level (bgl). The rig supply bores will provide water for hydraulic fracturing and well construction.

The expected total demand from the rig supply bores at any at each well site is 33,400 kiloliters (kL) produced over a 6-month (182-day) period, which equates to a consistent pumping rate of 183.52 cubic meters per day (m^3/d) for 182 days. It is also assumed that the rig supply bores will not represent an on-going demand upon the system, therefore, the groundwater models developed here only simulate a 182-day pumping period with an additional 270-day post-pumping recovery period. The models also assume that all ten sets of rig supply bores will operate concurrently. This is assumed to be a somewhat conservative approach as the wells will likely be installed in stages and there could be times when some rig supply bores are decommissioned before others are brought on-line.

The specific objective of the modelling is to estimate aquifer drawdowns induced by the rig supply bores and determine if there is a risk of groundwater production from the rig supply bores impacting existing bores in the area, creating excessive bore interference, or causing environmental impact to local groundwater dependent ecosystems (GDE).

2.0 Site Hydrogeology and Conceptual Model

The site sits near the northeast flank of the Fitzroy Trough within the Canning Basin geological region (**Figure 2-1**). The surface geology for the Canning Basin (**Figure 2-2**) indicates that the middle-to-late Permian Liveringa Group aquifer system is exposed at the surface at and around the project site. The Liveringa Group is comprised mostly of siltstone and limestone but also contains minor sandstone and thin coal beds (Lindsay and Commander, 2005). The Liveringa group is considered unconfined with some localized semi-confining units. The Liveringa is underlain by a regional aquitard called the Noonkanbah Formation, which overlays the Poole

Sandstone, which in turn overlays the Grant Group. The Grant Group and Poole Sandstone are both considered to be regional aquifer systems that are generally confined by the Noonkanbah Formation. For this evaluation, they are grouped together as a single aquifer unit. A block diagram showing the relationship between the aquifer formations within the Fitzroy Trough are shown on **Figure 2-3**, with a general location of the section line for the edge of the diagram on Figure 2-2. The Liveringa Group and the Grant/Poole aquifer systems are considered for this study in the event that both aquifers could supply water for the rig supply bores.

The potentiometric surface for the Grant/Poole aquifer system (**Figure 2-4**) indicates that hydraulic heads in the Development Envelope are 75-100 mAHD with a regional gradient from southeast to northwest. Ground surface elevations within the Development Envelope range from about 80 mAHD in the southwest corner to 145 mAHD along the northeast boundary; therefore, typical depths to groundwater in the Grant/Poole aquifer system are 5 to 45 m below ground surface (bgs). The potentiometric contours also suggest that groundwater is discharging to the mainstem and some tributaries of the Fitzroy River. A detailed study of groundwater-surface water interactions in an approximately 100-km reach of The Fitzroy River running to the south of the project site was presented in Harrington et al. (2011). Harrington et al. (2011) determined that The Fitzroy River is a gaining stream system that receives about 102 ML/day of groundwater inflow, with most of this flow (98.3 ML/d) derived from local sources representing recent recharge and shallow flow system. Harrington et al. (2011) also determined that fault zones in the system are providing preferential pathways for discharge from the deeper Grant/Poole system into the surface waters, which confirms that discharge is occurring from the Grant/Poole into the surface waters.

A regional potentiometric surface for the Liveringa is not available. Harrington et al. (2011) indicate that groundwater flow in the Liveringa is likely controlled locally by flow to surface waters in the Fitzroy River catchment with regional westward gradients like those in the Grant/Poole system.

Water quality data presented in Taylor et al. (2021) is relatively sparse for the aquifers near the project site, and there is insufficient data or information to determine if there are vertical interactions between the two formations or to develop aquifer parameters to model any vertical flows between the aquifers. For the evaluation described here, the two formations are assessed separately, and it is assumed that any vertical flows induced by pumping on one aquifer will not result in long-term impacts to the other aquifer.

The primary GDEs that could potentially be impacted by pumping from the proposed rig supply bores are associated with the main stem and tributaries of The Fitzroy River, with specific focus on Mount Hardman Creek given its proximity to the proposed rig sites. The proposed rig sites are all greater than 20 km from The Fitzroy River, and it is unlikely that temporary groundwater production from those bores will have any significant impact on GDEs associated with the Fitzroy River. Mount Hardman Creek is located approximately 1km away from the Muspelheim rig site and as such this well will be evaluated using the models described in subsequent sections.

3.0 Modelling Approach

A set of numerical groundwater models were developed using MODFLOW 6[1]. The Groundwater Vistas (ESI) modeling software was used to develop the input files and process model output. Two primary models were developed, one simulating the unconfined Liveringa Group (Mod 1) and one simulating the confined Grant/Poole aquifer system (Mod 2). Each model included a single

[1] https://www.usgs.gov/software/modflow-6-usgs-modular-hydrologic-model

model layer, with Mod 1 assigned an unconfined layer condition and Mod 2 assigned a confined layer condition. Each model grid shared the same footprint, with a 1000 x 1000-meter row and column spacing that was refined to about 62 x 62 m spacing within the development envelope using quadtree mesh refinement (**Figure 3-1**). Grid refinement within the development envelope was used to allow for more precise representation of the modeled impacts from the proposed rig supply bores.

The south and west boundaries in each model were assigned CH model cells (Figure 3-1) with heads designed to develop a similar hydraulic gradient as presented in Figure 2-4. Since the actual drawdown impacts presented in Section 5 below are very small and localized, it is assumed that the regional hydraulic gradients won't have a significant effect on drawdowns around the project site; therefore, the model is not expected to be particularly sensitive to the regional gradient. For Mod 1, a set of boundaries simulating Fitzroy Creek (Figure 3-1) were included with elevations based on the typical stage elevations obtained from Google Earth. These cells were not included in Mod 2. The model assumes that the northeast and southwest boundaries of the model domain are no-flow boundaries which are determined by the extent of active model cells (Figure 3-1).

The Liveringa Group aquifer is unconfined; therefore, the

saturated thickness of the Liveringa is the difference between the water table elevations and the elevations of the base of the aquifer. Water levels for the Liveringa are not available. Taylor et al. (2021) indicate that groundwater in the Liveringa is generally flowing in a westerly direction with discharge to the Fitzroy River. Pre-development water levels in the aquifer were based on Fitzroy River stage elevations and a general westerly hydraulic gradient. Static water levels for Mod 1 were estimated based on a steady-state model simulation dependent upon Fitzroy River stage elevations, which results in Liveringa water levels ranging from about 70 to 85 mAHD at the project site. These values are slightly lower than the values of 75 to 100 mAHD for the Grant/Poole system presented in Taylor et al. (2021; see Figure 2-4), which is consistent with upward hydraulic gradients in the system identified by Taylor et al. (2021).

The elevation of the base of the Liveringa within the Fitzroy Trough ranges from -84 to -171 mAHD (Rockwater, 2016). A representative value of -100 mAHD was therefore assigned to Mod 1. This indicates that the initial saturated thickness of the LIveringa within the development envelope is about 170 to 185 meters.

The Grant/Poole aquifer system is assumed to be confined throughout majority of the model domain and is therefore simulated in Mod 2 using a single model layer assigned a confined layer condition. The thickness and elevations of the aquifer system are variable and are not known at the project site; therefore, the aquifer is simulated assuming a constant transmissivity rather than a hydraulic conductivity and thickness. Transmissivity is defined as the product of the hydraulic conductivity and the saturated thickness. Transmissivity estimates were based on ranges of values presented in Taylor et al. (2021) as discussed below in Section 4.

An attempt was made to incorporate recharge into Mod 1 using the mean recharge estimate of 1.8 mm/yr presented in Taylor et al. (2021) calibrated to estimated groundwater discharge to the Fitzroy River (~100 ML/d over a 100 km reach) by varying hydraulic conductivity in a steady-state version of the model. The results indicate that, given the assumed geometry of the system, the regional hydraulic conductivity of the Liveringa would need to be unrealistically high to match the expected groundwater discharge rate and produce a reasonable water table in the model. Recharge was therefore not included in the final predictive model. This is considered acceptable as it provides a more conservative estimate of the potential impacts from the proposed pumping bores.

4.0 Model Inputs

4.1 Aquifer parameters for the Liveringa (Mod 1)

Hydraulic conductivity (K) values for the Liveringa Group formations as presented in Taylor et al. (2021) range from 3.25 x 10^{-5} to 0.0913 m/d. Rockwater (2016) used model calibration to drawdown data from nearby pumping bores to determine a representative K of 0.05 m/d for the Liveringa. This value is at the higher end of the range presented in Taylor et al. (2021), which is consistent with the high K values suggested by our attempted calibration to recharge and discharge estimates for the aquifer. A K of 0.05 m/d was therefore assumed for Mod 1.

Taylor et al. (2021) present porosity estimates for various formations in the Fitzroy Trough and assume a representative porosity of 0.05 for the Liveringa Group. This is equal to the value for specific yield (Sy) used by Rockwater (2016) for their Liveringa drawdown model. A Sy of 0.05 was therefore assumed for Mod 1.

4.2 Aquifer parameters for the Grant Group/Poole (Mod 2)

Thickness variations are uncertain in the Grant/Poole aquifer system; therefore, the Grant/Poole system was modeled assuming a homogeneous transmissivity (T) rather than hydraulic conductivity and thickness. Taylor et al. (2021) indicates T values from aquifer tests ranging from 6 to 525 m^2/d. A representative regional transmissivity for the aquifer is likely in the middle to upper part of this range of values; therefore, an intermediate value of 265 m^2/d was applied to the predictive model.

Mod 2 assumes a fully confined aquifer condition for the active model layer; therefore, the relevant aquifer storage coefficient is the storativity (S), which is defined as the product of the saturated thickness and the specific storage (Ss). Taylor et al. (2021) states that, for the Poole sandstone, "...specific storage has been derived for one location and is 0.001." This statement is assumed to be a typographical error as a) specific storage should have units of 1/length (e.g., 1/m) and b) a value of 0.001 is reasonable for S (which is a dimensionless quantity) for a sandstone aquifer but is 2 to 4 orders of magnitude too high for a reasonable specific storage value in a confined sandstone. This value is therefore assumed to represent the measured value for storativity and was therefore assigned to the Grant/Pool aquifer system model.

4.3 Predictive Simulations

The predictive models were set up with a ~6-month (182-day) stress period with active pumping and a ~9-month (270-day) recovery period with no pumping. Pumping was applied to each of the rig site locations shown in Figure 1-1 at 183.516 m^3/d, which is the rate required to produce a total of 33,400 kL over a 182-day period.

5.0 Model Results

Model results are presented as mapped drawdown contours with a minimum contour of 0.2 meters and a 0.2-m contour interval. Drawdown is defined as the change in water levels within the aquifers (i.e., below ground surface) that results from pumping of the proposed production wells. The value of 0.2 was chosen for the minimum because normal seasonal fluctuations are likely on the order of 0.2 to 1 m; therefore, any values less than 0.2 m are likely not significant relative to natural variations. Locations of known existing bores within and near the project site are also shown on the maps of model results to determine potential impact to existing bores.

Figure 5-1 shows modeled drawdowns at the end of the 6-month pumping period for Mod 1. Modeled drawdowns at the pumping bores range from 7.3 m to just under 8 m. The radius of the 0.2-m drawdown contour for each bore is within 500 m of each pumping bore. All 0.2-m drawdown contours are greater than a kilometer from any existing bores in the project area. Mod 1 indicates that production of the required volumes of water should not result in any observable impacts to existing bores.

Figure 5-2 shows modeled drawdowns at the end of the 6-month pumping period for Mod 2. The 0.2 m contour interval extends throughout much of the project site and encompasses two of the known existing bores in the project area. Model-predicted drawdowns at those bores range from 0.2 to 0.3 m, which is smaller than the normal seasonal variations in water levels and which represents a very small percentage of the available water column in each bore. Drawdowns in the bores that exceed 0.2 m recover to residual drawdowns between 0.08 and 0.16 m within nine months of the end of pumping.

An additional set of predictive model simulations for both Mod 1 and Mod 2 were performed with pumping only applied to the Muspelheim well location (labeled “Mus” on Figure 1-1). These simulations were performed to determine the radius of impact from an individual bore for each model. Model results are presented as distance-drawdown plots showing modeled drawdown after 6 months of continuous pumping at 183.516 m^3/d. Model results are presented in **Figure 5-3**. As indicated by **Figure 5-3A**, modeled drawdowns for Mod 1 (Liveringa aquifer) are 0.2 m at about 350 m from the pumping well, less than 0.1 m at just over 400 m from the pumping well, and less than 3E-06 m at 1,000 m from the pumping well. Model-calculated drawdowns in the Liveringa within 1-km of the Mus well for the single pumping well simulation are identical to the drawdowns from the simulation with all well locations pumping, which indicates that production from the rig supply bores at the expected rates will not result in inter-well drawdown interference. As indicated by **Figure 5-3B**, modeled drawdowns for Mod 2 (Grant/Poole aquifer) are 0.2 m at 3.25 km from the pumping well and 0.1 m at just over 10 km from the pumping well (Figure 5-3B).

The model results presented in Figures 5-1 through 5-3 suggest that the Liveringa aquifer should experience greater drawdowns at each well but with a much more limited extent of drawdown impact in the aquifer as compared to the Grant/Poole aquifer. This is consistent with the assumptions built into the model, as the Grant/Poole aquifer is expected to have a much higher hydraulic conductivity (which would result in less impact at the pumping wells) with a much lower storage coefficient associated with confined condition (which would result in a greater areal extent to drawdown impacts). In general, this result is expected as drawdowns in an unconfined aquifer (like Mod 1) are related to the production wells temporarily draining water out of the aquifer pore space right next to the well while production wells in a confined aquifer (like Mid 2) are temporarily depressurizing the aquifer, which will affect a larger area but result in smaller drawdowns at the actual wells.

6.0 Modeling Limitations and Sensitivity Analysis

The objective of the modelling presented here is to simulate pumping-induced drawdowns in an aquifer given a relatively short-term pumping period (~6 months) and general assumptions about the aquifer input parameters. The modelling software used for the simulations (MODFLOW) is an industry standard program that has been developed over 4 decades and that has been verified as an appropriate tool for simulating aquifer drawdowns in response to pumping.

A review of available literature and other data on the geology and hydrogeology of the study area indicates that there are two potential target aquifers at the site – the unconfined Liveringa and the underlying confined Grant/Poole. There is a considerable amount of uncertainty about groundwater conditions, boundary conditions, and aquifer parameters and parameter variability at the site, which in turn creates predictive uncertainty in the models. The uncertainty associated with critical aspects of the model and the approaches used for dealing with that uncertainty are discussed here.

6.1 General Modelling Approach

The total pumping demand built into the model assumes ten (10) rig supply bores each producing a given amount (33,400 kL) over a time period intended to represent the time required to install the associated hydrocarbon exploration bores (6 months) at each wellsite. For all simulations the modelling assumes that all 10 rig supply wells start pumping at the same time and operate concurrently for the same 6-month period. This is considered to be a conservative approach that results in a "worst-case" pumping application scenario as the actual exploration bores will likely be installed in stages over a multi-year period, which in turn would mean that rig supply bores will come on- and off-line over an extended period. This conservative approach helps to mitigate the uncertainty associated with other model inputs as the simulations are applying a much greater stress to the aquifer than what it will actually experience.

The system was modelled with individual one-layer models for each aquifer system rather than an integrated multi-layer model with some limitations on vertical inter-formational flows (e.g., an aquiclude or vertical anisotropy). The primary reason for this is because there is not enough available information in the literature and existing data to characterize inter-formational flows and verify that a modelling approach is adequately simulating reality. Using individual one-layer models and applying all expected pumping to each model results in a more conservative model as any interformational flows would likely result in additional water moving into the pumped formation, which in turn will reduce modelled drawdowns. This approach is therefore considered to be a conservative approach that will overstate actual aquifer drawdowns.

6.2 Boundary Conditions

Estimates of aquifer recharge to the unconfined system are available for the study area (see Section 3); however, there is considerable uncertainty associated with those estimates. Since applying recharge to the unconfined model would result in reductions to the modelled drawdowns, recharge was not included in the final modelling to create a more conservative estimate of predictive drawdowns.

Other model boundary conditions, such as the constant head cells to the south and west and the lateral no-flow boundaries to the northeast and southwest are positioned far enough from the Development Envelope that they do not have any notable impact on drawdowns within the study area.

6.3 Aquifer Parameters

Mod 1 assumes unconfined aquifer conditions; therefore, the hydraulic conductivity (K) and the specific yield (Sy) are the key aquifer parameters for that model. Mod 2 assumes confined aquifer conditions; therefore, the transmissivity (T) – which is the product of the hydraulic conductivity and the saturated thickness – and the storativity (S) – which is the product of the elastic storage coefficient and the saturated thickness – are the key aquifer parameters for that model. Estimates of appropriate values for these parameters, as derived from the available literature, are presented in Section 4.

The estimates presented for K and T in each aquifer system are broad ranges of values that cover several orders of magnitude. For the storage parameters there are very few estimates that generally cover typical values for the aquifer conditions and lithologies present at the site. The uncertainty associated with aquifer parameters is addressed through a model sensitivity analysis that involves a large number of simulations with variations in permeability, storage parameters, and pumping rates, with results presented as drawdown statistics for the proposed production bores and existing off-site bores.

6.3.1 Sensitivity Analysis – Mod 1

Table 6-1 shows a summary of the input values for the sensitivity analysis simulations for Mod 1. The input parameters varied include the total pumping rates, with four sets of pumping rates equivalent to 50%, 100%, 150%, and 300% of the expected rates described in Section 1 (183.52 m^3/d per well over 6 months); three sets of K values ranging from 1.0E-05 to 1.0E-01 m/d; and three sets of Sy values ranging from 0.01 to 0.3.

Sensitivity analysis results for Mod 1 are presented in Table 6-1. The column "Avg at Pumping Bores" in Table 6-1 contains the average modelled drawdowns at the actual pumping bores at the end of the pumping period in each simulation. As indicated on Table 6-1, drawdowns at the pumping wells are sensitive to variations in K with significantly larger drawdowns at the lower K values. For the simulations at 50% or 100% of expected pumping, the lower K models result in relatively large (~20-60 m) drawdowns at the pumping wells, however, these values are still less than the assumed initial saturated thickness (~170-185 m). There is some uncertainty in the actual saturated thickness at the site; however, even if it is half of the assume thickness (85-90 m) the modelled drawdowns from the models with 50-100% of expected pumping will not exceed the available.

At the highest pumping rates, the modeled drawdowns can be a significant fraction of available saturated thickness; therefore, greater pumping rates will only be sustainable if the K values are similar to those assumed for the models presented in Section 4 and 5.

For all 36 simulations the modeled drawdowns at each existing bore (see Figure 5-1 for existing bore locations) were 0.01 m or less, which is considered to be less than the resolvable precision of the model and is interpreted to indicate no impact from pumping on existing bores. This suggests that, even with the most conservative conditions, pumping from the proposed bores completed in the unconfined system will not result in any observable impacts to existing bores.

6.3.2 Sensitivity Analysis Results – Mod 2

Table 6-2 shows a summary of the input values for the sensitivity analysis simulations for Mod 2. The input parameters varied include the same ranges of total pumping rates; three sets of T values ranging from 10 to 1,000 m^2/d, and three sets of S values ranging from 1.0E-04 to 1.0E-02.

Sensitivity analysis results for Mod 2 are presented in Table 6-2. The column "Avg at Pumping Bores" in Table 6-2 contains the average modelled drawdowns at the actual pumping bores at the end of the pumping period in each simulation. As indicated on Table 6-2, drawdowns at the pumping wells are sensitive to variations in both T and S, though the differences in drawdowns at the lower values are not as significant as those indicated in Mod 1. Overall drawdowns at the pumping bores are not as extreme as those observed in Mod 1 and given that the expected completion depths for production bores in the Grant/Poole aquifer will be much deeper than those in the Liveringa (likely >200 m below ground level), the model simulations indicate that there will be sufficient available water column in the production bores for even the lowest expected aquifer parameters.

The columns containing "… at Existing Bores" in Table 6-2 contain general statistics for the modelled drawdowns at the existing bores shown in Figure 5-2. Drawdowns at existing bores are less than 4.5 m for all simulations at 50-100% of expected pumping, with all models but the lowest S values resulting in drawdowns less than 1 meter. The models indicate that the greatest sensitivity is to storativity, with the lowest S values generally resulting in drawdowns greater than a meter throughout the Development Envelope. These results indicate that there could be some risk of impact to existing bores if the actual aquifer parameters in the Grant/Poole are much lower than expected; however, those impacts will certainly be minimized if pumping from the production bores is distributed over time as expected.

7.0 Conclusions and Proposed Future Work

The results of Mod 1 indicate that production of the required water volumes from the Liveringa Group will not result in any noticeable impact to existing bores at the project site. The nearest GDE (Mt. Hardman Creek) is also too far from the nearest proposed rig site to experience any significant impacts from the proposed project.

The results from Mod 2 indicated that production of the required water volumes from the Grant/Poole aquifer system would potentially induce temporary drawdowns between 0.2 and 0.4 m on a small number of existing bores at the project site. These drawdowns will likely recover within a year after the end of the pumping period. The impacts represent a very small percentage of the available water column in each bore and would likely not induce any practical impact on the operation of the existing bores.

Hydraulic heads in the Grant/Poole system are higher than those in the overlying Liveringa, which suggests that there could be vertical upward flow of groundwater between the two systems. The evaluations presented by Harrington et al. (2011) also indicate that there is some flow moving up along fault zones and discharging into the Fitzroy River. There is insufficient data to adequately model any interactions between the two aquifer systems; therefore, this was not included in the modeling analysis. Due to the short-term nature of the proposed pumping and the relatively small impacts on each aquifer from pumping within each aquifer, it is unlikely that there would be significant cross-formational impacts from pumping in either aquifer.

Sensitivity analysis of the critical input parameters for Mod 1 indicates that there is very little risk of pumping from the Liveringa affecting any existing bores; however, the aquifer may not be able to support production at higher pumping rates. All Mod 1 sensitivity analysis simulations resulted in modeled drawdowns at the existing bores that are so small they are likely beyond the reasonable resolution of the modelling.

The Mod 2 (Grant/Poole aquifer) sensitivity analysis indicates that the aquifer should not have any problem supplying the required water even at 3 times the expected rates; however, the Grant/Poole aquifer model is sensitive to variations in model storativity and lower than expected storativity in the actual aquifer could result in existing bores temporarily experiencing 1 to 15 m of drawdown by the end of the 6-month pumping period. Drawdown contours were not generated for each of the sensitivity analysis simulations; however, the drawdown statistics presented in Section 6 indicate that typical drawdowns at existing wells for the 100% demand simulations are much less than 1 meter for all but the most restrictive input parameters.

Groundwater levels at each site are generally within 5-45 m of ground surface and each aquifer should have well over 100 m of saturated thickness (i.e., water level in wells above the base of the aquifer) available for drawdown. The modeled drawdowns for all sensitivity analysis simulations, therefore, are expected to be a small percentage of the available drawdowns, which in turn indicates that the modelled impacts are relatively small.

The analysis presented here is conservative for several reasons:

- The modeling approach assumes that to all rig supply bores pumping concurrently, which will likely not happen as construction of the wells will likely be staged over time.
- The required pumping involves producing a finite volume of water over a relatively short period of time. Any observed impacts at existing pumping bores should recover to pre-pumping rates within a year of the end of pumping.
- Recharge is not included in any of the model simulations. Adding recharge to the system would reduce modeled impacts from pumping.
- The models assume that all pumping is applied to either the Liveringa or the Grant/Poole. If the required pumping is distributed between the two formations, the overall impacts to each formation will be reduced.

The modeling presented here was developed using data and information from the literature with no site-specific testing or investigations. Aquifer testing, including step-drawdown and constant rate pumping tests, should be performed on each of the groundwater extraction bores shortly after installation and development are completed. If possible, at least one monitoring bore should be installed close enough to a production bore to allow for at least one multi-bore aquifer test to establish storage parameters at the site. The results of site-specific testing should then be used to refine the model calculations and develop more reliable estimates of future impacts at the site.

8.0 References

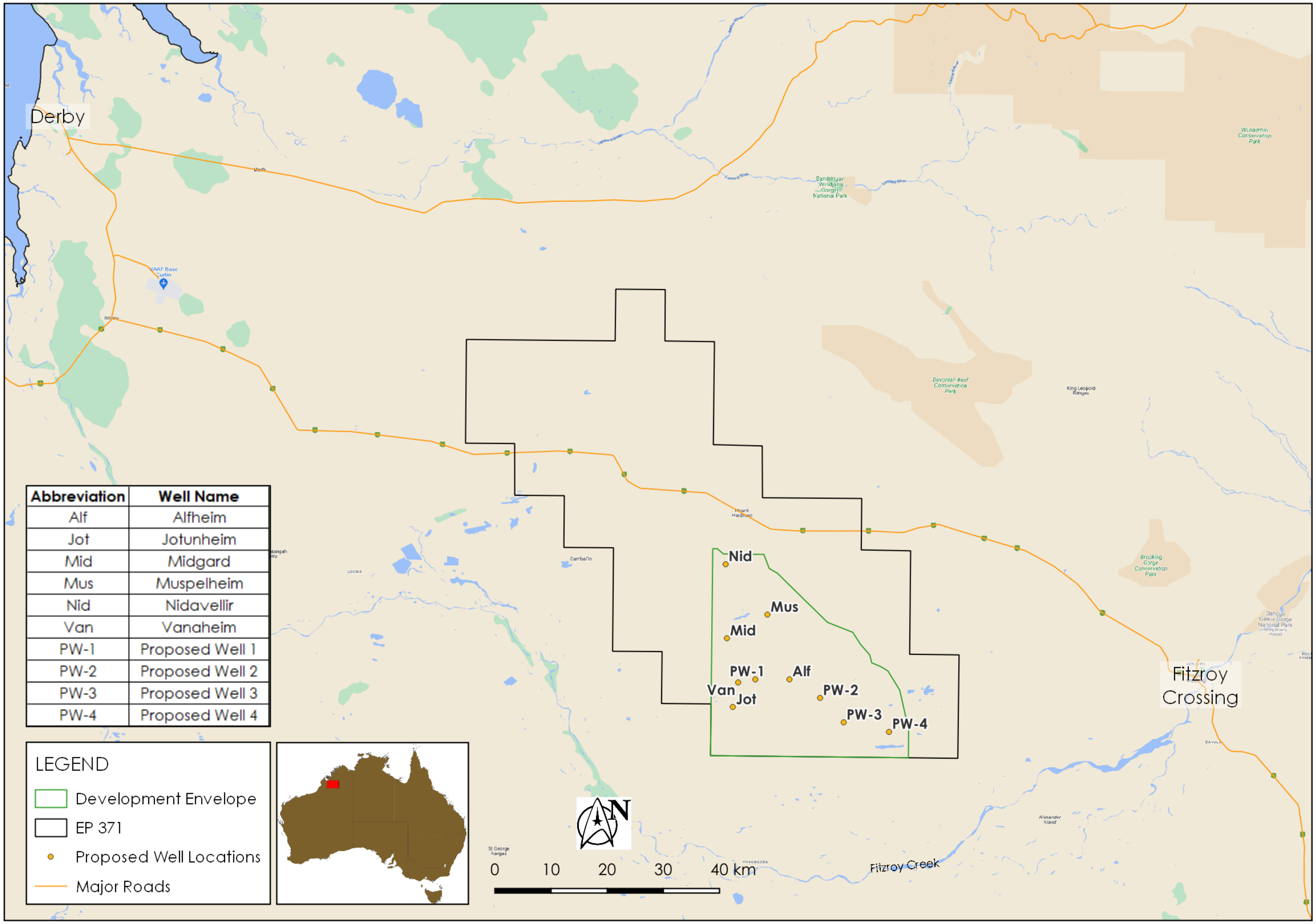
Harrington, G.A., Stelfox, L., Gardner, W.P., Davies, P., Doble, R. and Cook, P.G. 2011. Surface water – groundwater interactions in the lower Fitzroy River, Western Australia. CSIRO: Water for a Healthy Country National Research Flagship. 54 pp.

Lindsay, R.P. and Commander, D.P., 2005. Hydrogeological Assessment of the Fitzroy Alluvium, Western Australia, Department of Water, Hydrogeological Record Series HG 16., https://www.water.wa.gov.au/__data/assets/pdf_file/0018/4824/77811.pdf.

Rockwater, 2016. Hydrogeological Assessment of Paradise–Valhalla–Asgard Project Areas; Report No. 416.0/16/04b prepared for Buru Energy, 26 p. plus Appendix I.

Taylor, A.R.; Barron, O.V.; Mule, S.; and Ibrahimi, T.; 2021. Groundwater baseline review of the Canning Basin, Western Australia. A technical report from CSIRO to GISERA. CSIRO Technical Report EP2021-1700; CSIRO, Australia. https://doi.org/10.25919%2Fwsky-g072

Figures



Abbreviation	Well Name
Alf	Alfheim
Jot	Jotunheim
Mid	Midgard
Mus	Muspelheim
Nid	Nidavellir
Van	Vanaheim
PW-1	Proposed Well 1
PW-2	Proposed Well 2
PW-3	Proposed Well 3
PW-4	Proposed Well 4

Figure 1-1. Map of the overall study area and locations of the proposed gas production wells

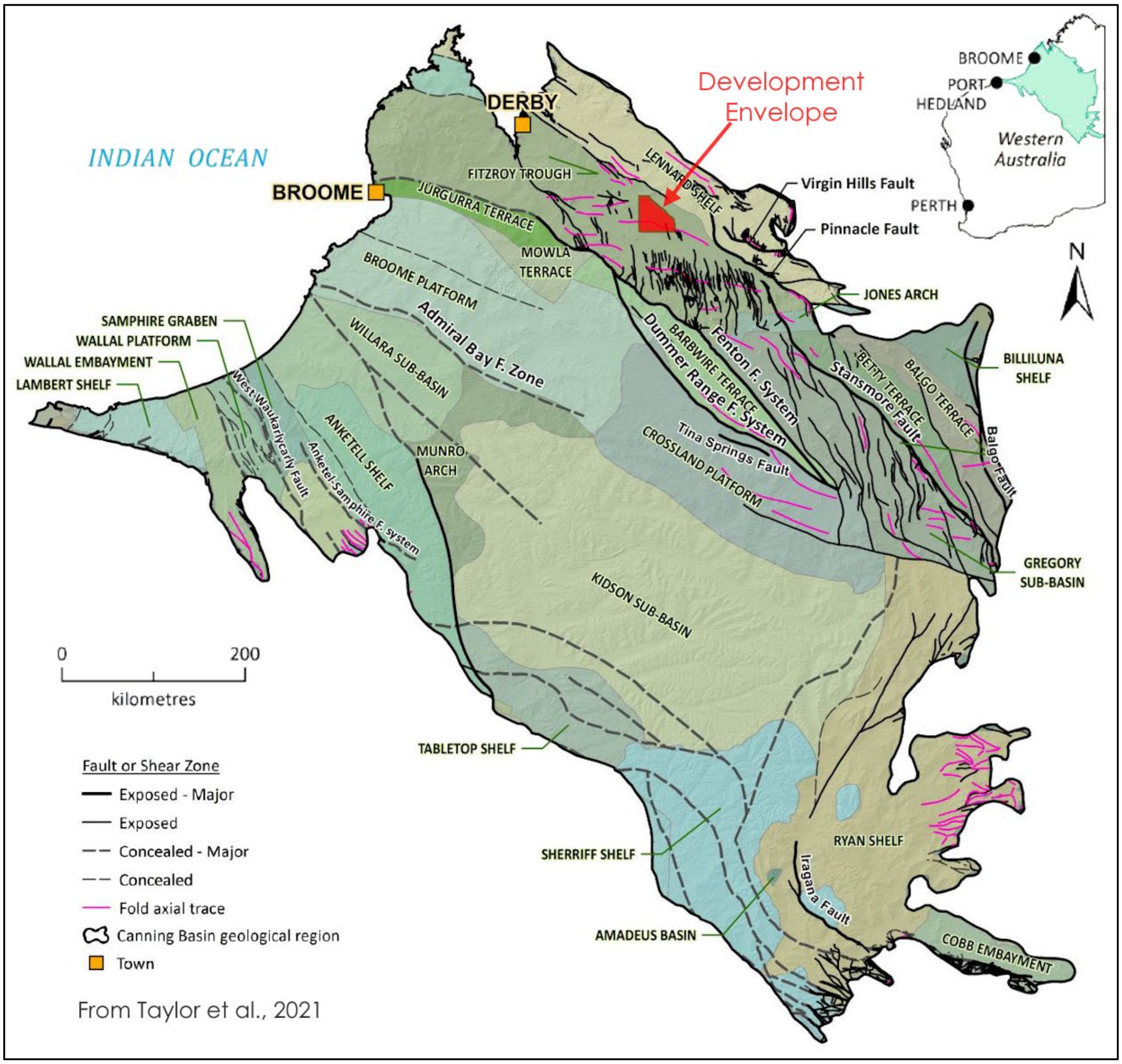


Figure 2-1. Tectonic and structural elements of the Canning Basin

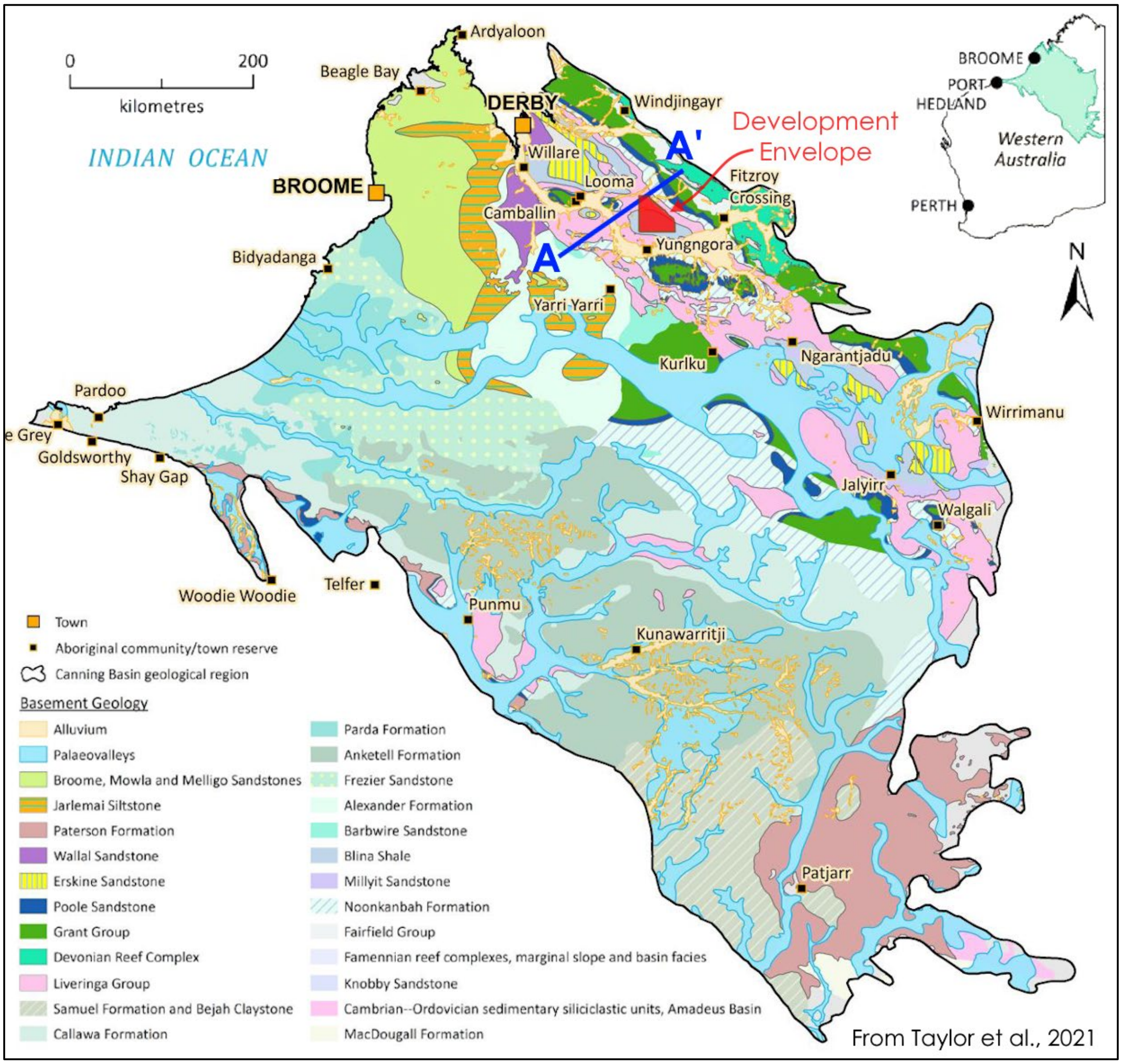


Figure 2-2. Surficial geology within the Canning Basin. The general location of the face of the block diagram in Figure 2-3 is represented by section line A-A'

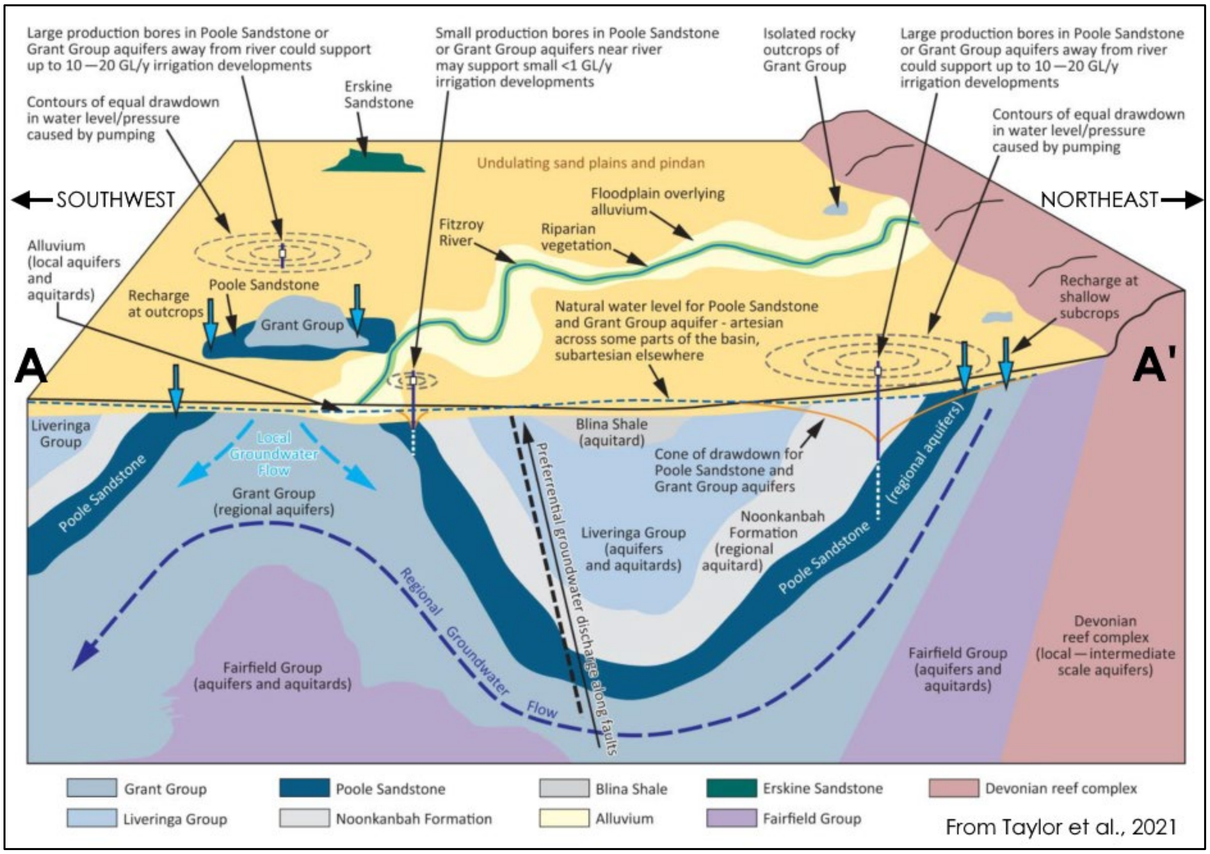


Figure 2-3. Simplified conceptual hydrogeologic block model showing the key aquifers within the Fitzroy Trough. The general location of the section that corresponds to the face of the block diagram is show as the blue line (A-A') on Figure 2-2.

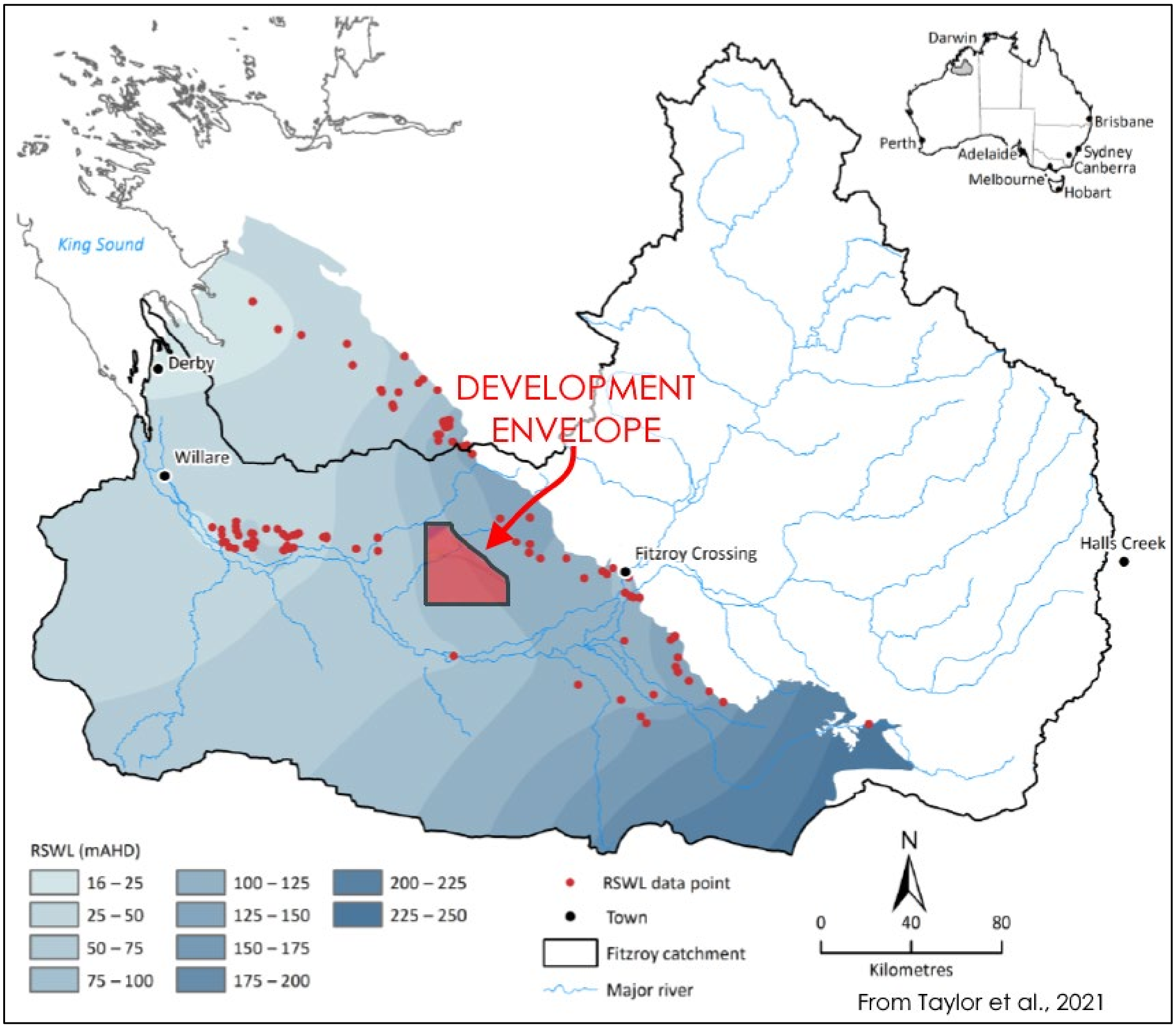


Figure 2-4. Potentiometric surface for the Grant Group and Poole Sandstone aquifers.

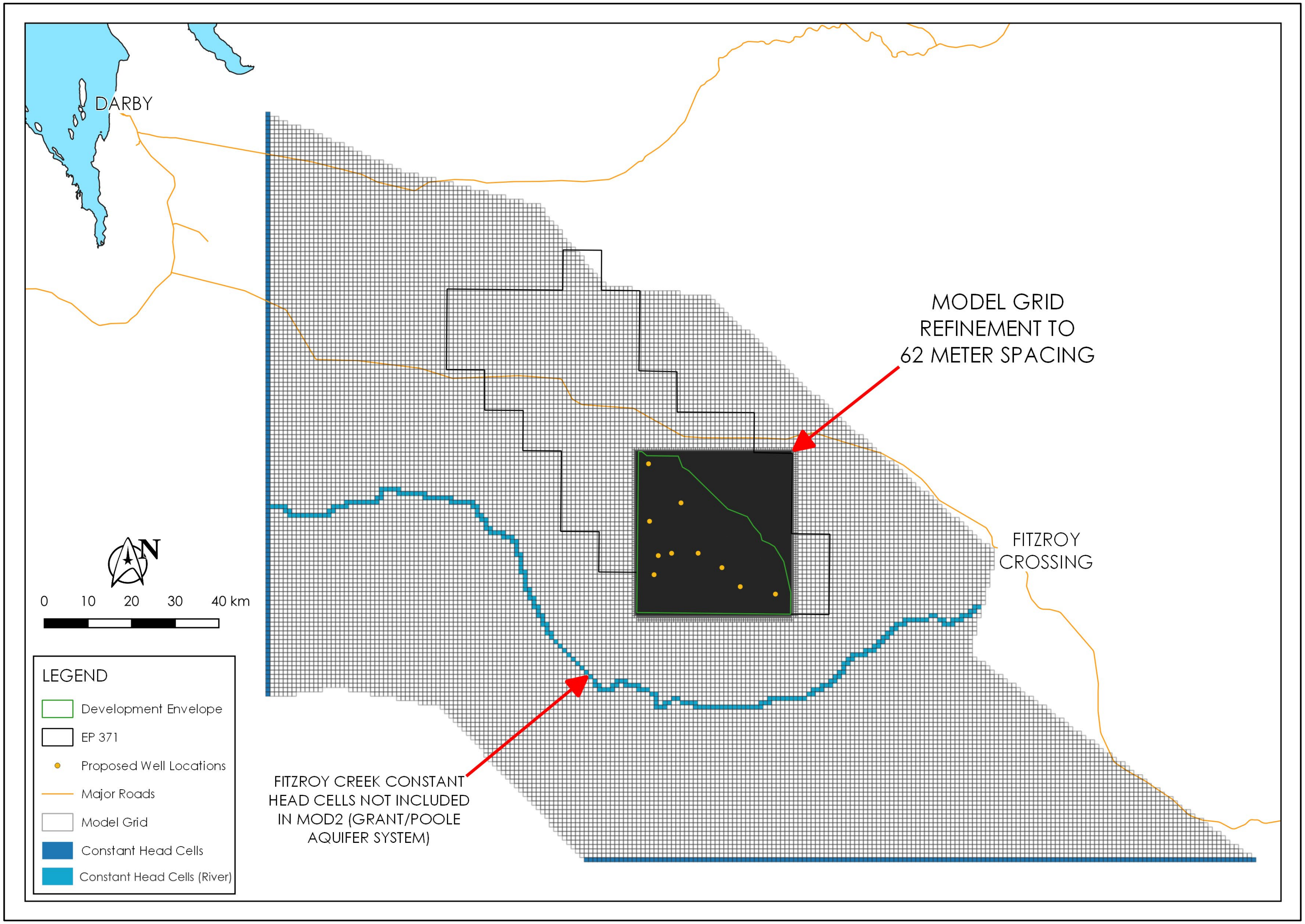


Figure 3-1. Map of MODFLOW 6 unstructured model grid with grid refinement within the development envelope.

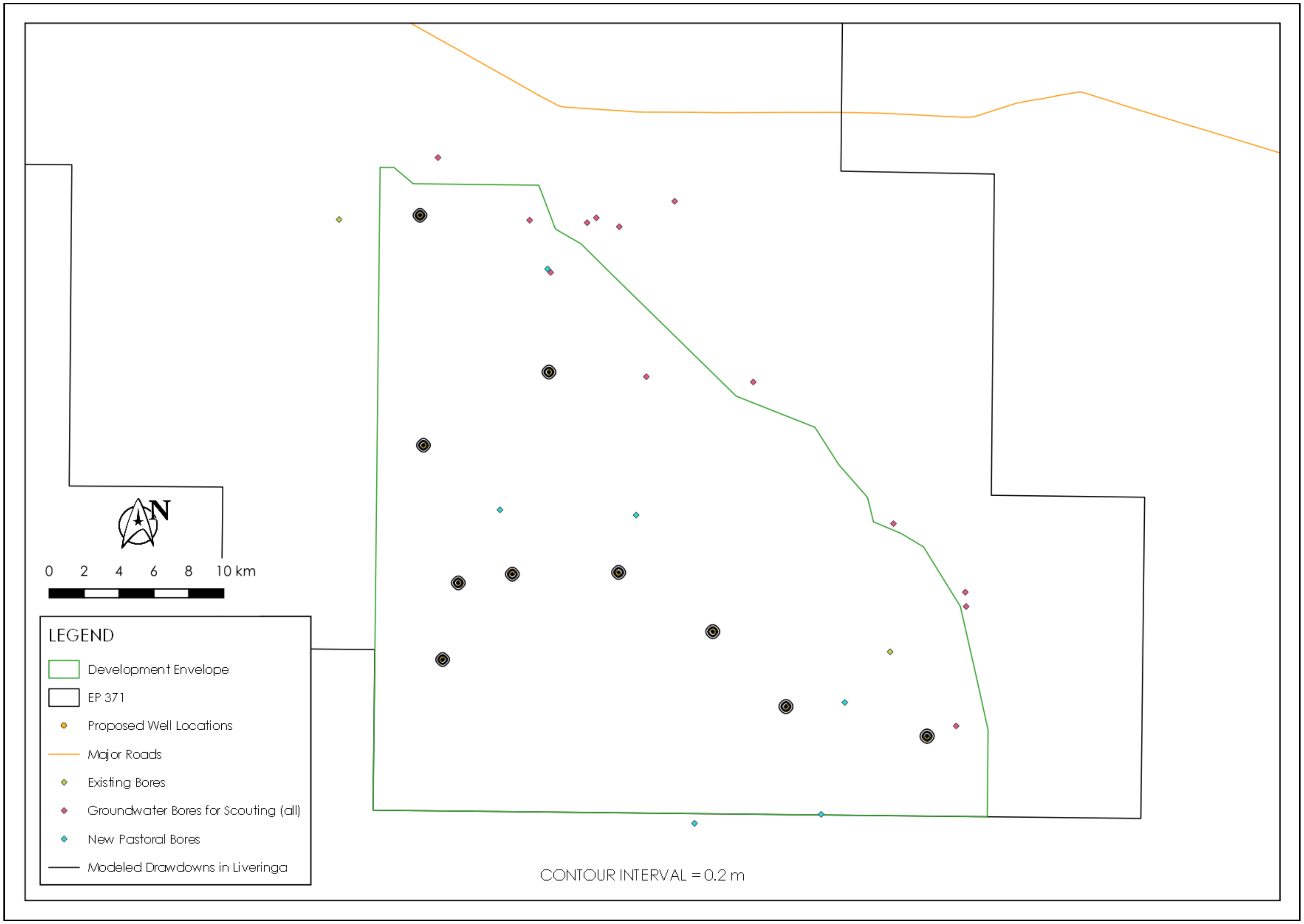


Figure 5-1. Mod 1 model results presented as drawdown contours after 6 months of pumping with contour interval = 0.2 meter.

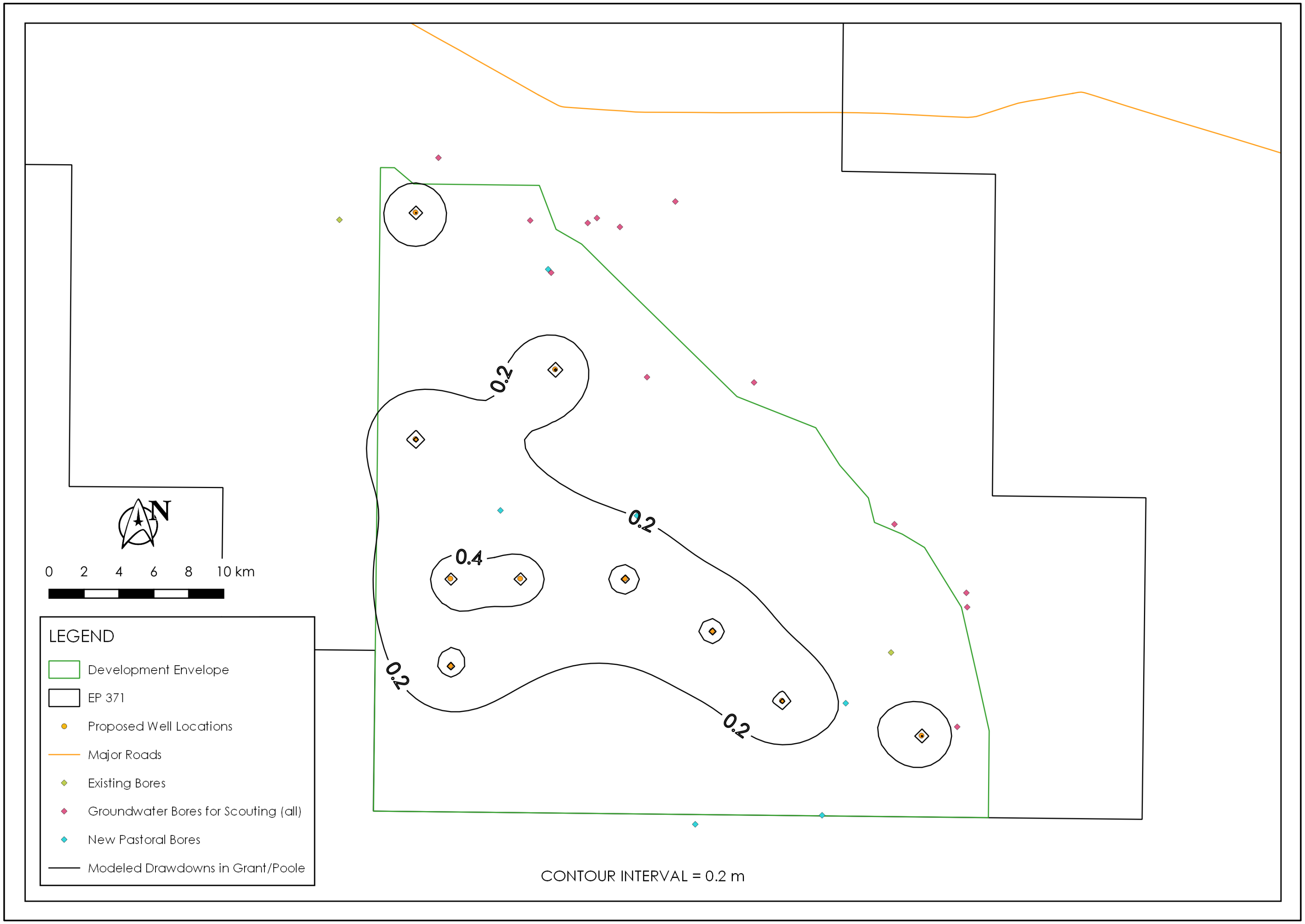


Figure 5-2. Mod 2 model results presented as drawdown contours after 6 months of pumping with contour interval = 0.2 meter.

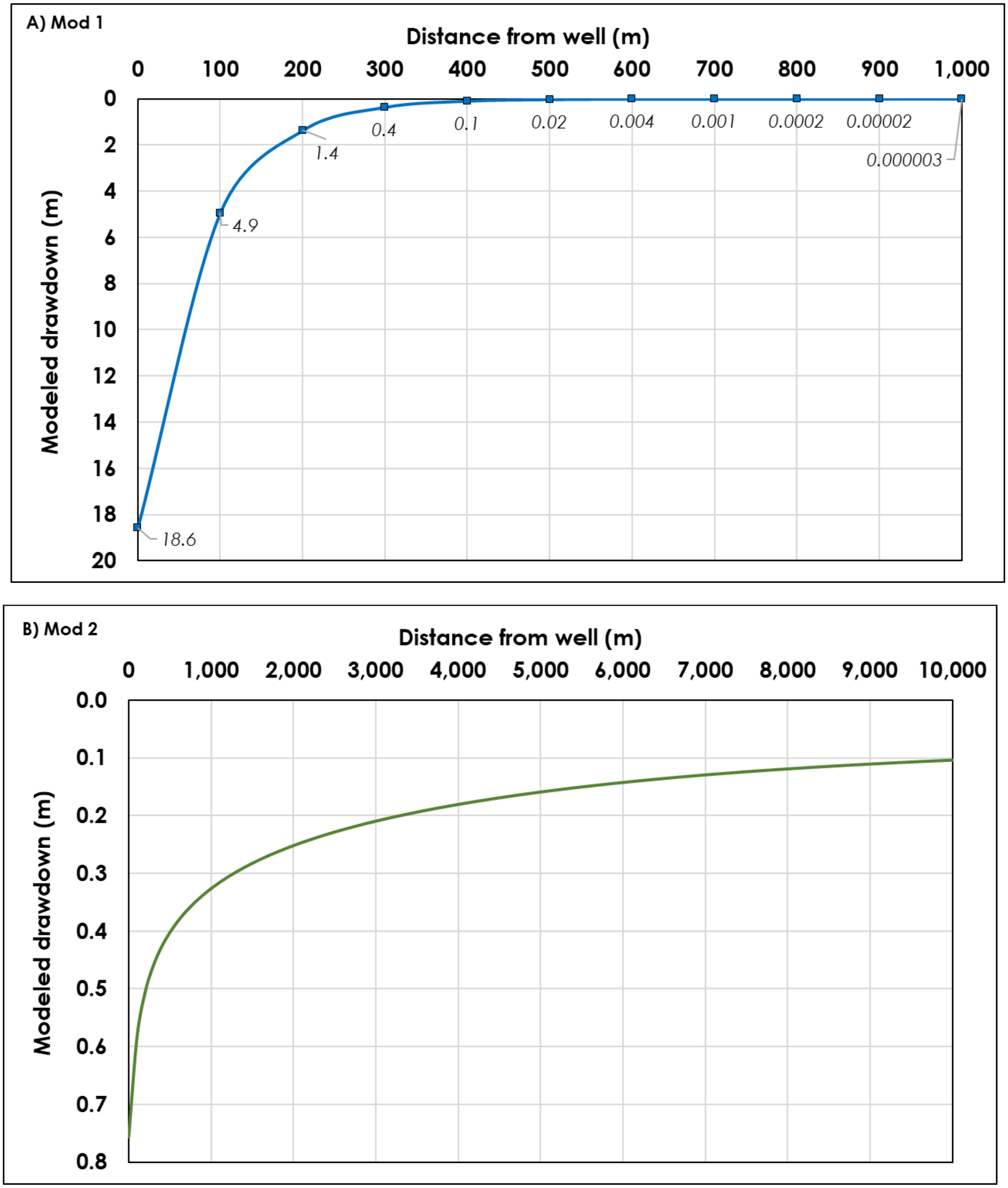


Figure 5-3. Model results presented as distance-drawdown plots after 6 months of pumping for the A) Mod 1 and B) Mod 2 simulations with pumping only applied to a single well. The *italic* numbers on A) are the modelled drawdowns at 100-m intervals from the pumping well.

Tables

Table 6-1. Summary of model sensitivity analysis for Mod 1. Values in column 5 are modelled drawdowns at the pumping bores. Sim00 is the model described in Section 4 & 5.

Sim No.	Q kL/d	K m/d	Sy	Avg at Pumping Bores m	Notes
Sim01		0.00001	0.01	**25.2**	
Sim02			0.1	**16.2**	**Pumping rate is**
Sim03			0.3	**9.2**	**sustainable for all**
Sim04	**91.758**	0.001	0.01	**22.8**	**modeled conditions**
Sim05	**50%**		0.1	**15.2**	
Sim06			0.3	**8.8**	**Modeled drawdowns are**
Sim07		0.1	0.01	**2.3**	**<0.01 m at existing bores**
Sim08			0.1	**2.1**	
Sim09			0.3	**1.9**	
Sim10		0.00001	0.01	**55.3**	
Sim11			0.1	**33.5**	**Pumping rate is**
Sim12			0.3	**18.5**	**sustainable for all**
Sim13	**183.516**	0.001	0.01	**49.5**	**modeled conditions**
Sim14	**100%**		0.1	**31.3**	
Sim15			0.3	**17.8**	
Sim00		**0.05**	**0.05**	**7.7**	**Modeled drawdowns are**
Sim16		0.1	0.01	**4.6**	**<0.01 m at existing bores**
Sim17			0.1	**4.3**	
Sim18			0.3	**3.8**	
Sim19		0.00001	0.01	**95.2**	**Pumping rate is**
Sim20			0.1	**52.2**	**sustainable for all**
Sim21			0.3	**28.1**	**conditions, but could**
Sim22	**275.274**	0.001	0.01	**84.0**	**be marginal for the**
Sim23	**150%**		0.1	**48.8**	**lowest Sy values**
Sim24			0.3	**27.1**	
Sim25		0.1	0.01	**7.0**	**Modeled drawdowns are**
Sim26			0.1	**6.4**	**<0.01 m at existing bores**
Sim27			0.3	**5.7**	
Sim28		0.00001	0.01	***169.6***	*Pumping rate is not sustainable*
Sim29			0.1	***121.4***	*Significant loss of sat. thickness*
Sim30			0.3	**58.1**	
Sim31	**550.548**	0.001	0.01	***170.0***	*Pumping rate is not sustainable*
Sim32	**300%**		0.1	***114.7***	*Significant loss of sat. thickness*
Sim33			0.3	**56.0**	**Pumping rate is sustainable**
Sim34		0.1	0.01	**14.2**	**for all other conditions.**
Sim35			0.1	**13.1**	**Modeled drawdowns are**
Sim36			0.3	**11.4**	**<0.01 m at existing bores**

Table 6-2. Summary of model sensitivity analysis for Mod 2. Values in columns 5-8 are modelled drawdowns at the pumping bores and existing bores. Sim00 is the model described in Section 4 & 5.

Sim No.	Q kL/d	T m²/d	S	Avg at Pumping Bores m	Min at Existing Bores m	Avg at Existing Bores m	Max at Existing Bores m	Notes
Sim01		10	0.0001	**9.9**	**0.1**	**0.7**	**2.2**	**Pumping rate is sustainable for all modeled conditions**
Sim02			0.001	**7.4**	**0.0**	**0.0**	**0.3**	
Sim03			0.01	**5.7**	**0.0**	**0.0**	**0.0**	
Sim04	**91.758**	100	0.0001	**1.7**	**0.3**	**0.5**	**1.1**	
Sim05	**50%**		0.001	**0.9**	**0.0**	**0.0**	**0.1**	**Drawdowns greater than one meter at existing bores for lowest storativity range**
Sim06			0.01	**0.7**	**0.0**	**0.0**	**0.0**	
Sim07		1000	0.0001	**0.2**	**0.0**	**0.0**	**0.1**	
Sim08			0.001	**0.1**	**0.0**	**0.0**	**0.0**	
Sim09			0.01	**0.1**	**0.0**	**0.0**	**0.0**	
Sim10		10	0.0001	**19.8**	**0.1**	**1.4**	**4.4**	
Sim11			0.001	**14.8**	**0.0**	**0.1**	**0.6**	**Pumping rate is sustainable for all modeled conditions**
Sim12			0.01	**11.5**	**0.0**	**0.0**	**0.0**	
Sim13	**183.516**	100	0.0001	**3.4**	**0.6**	**1.1**	**2.3**	
Sim14	**100%**		0.001	**2.0**	**0.0**	**0.1**	**0.4**	
Sim15			0.01	**1.5**	**0.0**	**0.0**	**0.1**	**Drawdowns greater than one meter at existing bores for lowest storativity range**
SIm00		**265**	**0.001**	**0.8**	**0.0**	**0.1**	**0.3**	
Sim16		1000	0.0001	**0.5**	**0.2**	**0.3**	**0.4**	
Sim17			0.001	**0.2**	**0.0**	**0.0**	**0.1**	
Sim18			0.01	**0.2**	**0.0**	**0.0**	**0.0**	
Sim19		10	0.0001	**29.8**	**0.2**	**2.1**	**6.7**	**Pumping rate is sustainable for all modeled conditions**
Sim20			0.001	**22.3**	**0.0**	**0.1**	**0.9**	
Sim21			0.01	**17.2**	**0.0**	**0.0**	**0.0**	
Sim22	**275.274**	100	0.0001	**5.2**	**0.9**	**1.7**	**3.4**	
Sim23	**150%**		0.001	**3.0**	**0.0**	**0.2**	**0.6**	**Drawdowns greater than one meter at existing bores for lowest storativity range**
Sim24			0.01	**2.2**	**0.0**	**0.0**	**0.1**	
Sim25		1000	0.0001	**0.9**	**0.4**	**0.5**	**0.7**	
Sim26			0.001	**0.5**	**0.1**	**0.1**	**0.3**	
Sim27			0.01	**0.3**	**0.0**	**0.0**	**0.1**	
Sim28		10	0.0001	**59.5**	**0.3**	**4.2**	**13.4**	**Pumping rate is sustainable for all modeled conditions**
Sim29			0.001	**44.5**	**0.0**	**0.2**	**1.9**	
Sim30			0.01	**34.4**	**0.0**	**0.0**	**0.0**	
Sim31	**550.548**	100	0.0001	**10.4**	**1.9**	**3.4**	**6.9**	
Sim32	**300%**		0.001	**5.9**	**0.0**	**0.4**	**1.3**	**Drawdowns greater than one meter at existing bores for lowest storativity range**
Sim33			0.01	**4.5**	**0.0**	**0.0**	**0.2**	
Sim34		1000	0.0001	**1.9**	**1.0**	**1.2**	**1.6**	
Sim35			0.001	**1.0**	**0.2**	**0.3**	**0.6**	
Sim36			0.01	**0.6**	**0.0**	**0.0**	**0.1**	