Submission to the Water Plan (Moreton) 2007 Amendment

Lockyer Water Users Forum Incorporated

Version: 25 January 2019

Introduction

The Lockyer Water Users Forum (LWUF) is a not for profit, advocacy body that represents all irrigators in the Lockyer Valley (in the Upper, Central and Lower Lockyer). LWUF's 225 formal members encompass all agricultural commodities grown within the valley as well as other value-add and service industries that are intrinsic to the Lockyer's economy.

This submission has been prepared based on:

- extensive consultations with members and key stakeholders located throughout the Lockyer Valley many of whom have also made separate individual submissions on the draft Water Plan
- scientific studies and expert facilitation services commissioned by the LWUF and wholly funded by members of the Lockyer Valley community including irrigators, local businesses, commodity buyers, and individual residents
- significant in-kind support relating to the above from the Lockyer Valley Regional Council.

These stakeholders all recognise the economic significance and are deeply concerned about the potential adverse impacts that the proposed water plan water allocations will have on the local economy and the social fabric of the Lockyer Valley.

Ten-point response to the draft amendment

The LWUF:

1. **totally rejects the draft amendment's proposal to implement differential groundwater water allocations (i.e. based on history of use)**.

   LWUF contend that this approach unfairly discriminates against property owners in transferring capital value from one landholder to another.

2. **also totally rejects the scientific basis – particularly the hydrologic data and model – upon which the draft amendments have been based**.

   An independent expert review commissioned by LWUF and undertaken by consultants hydrogeologist.com.au has found fundamental and systemic flaws in the department's data and hydrologic groundwater modelling approach which are detailed in the attached report "Report on High-level Review of the Central Lockyer Groundwater Model"[1] and tendered as part of – and in support of – this submission.

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[1] *Report on High-level Review of the Central Lockyer Groundwater Model*, hydrogeologist.com.au, January 2019.

Modelled aquifer recharge and extractions are both grossly under-estimated which in turn means that the overall available yield of the aquifer – upon which the draft plan's proposal allocations are based – are also grossly underestimated (estimated at around 100% on average but with even greater impacts in individual cases). In particular, Section 5 of hydrogeologist.com.au's review concluded, amongst other things, that:

a) the department's groundwater model "*is not fit for purpose for groundwater allocation and management and, in our opinion, is overdue for a replacement*"

b) in relation to the confidence in modelling outputs, uncertainties and/or limitations in modelling data inputs, assumptions, model set-up and overall technical approach, "*we have little confidence in the model solution presented in the department's groundwater model. The model solution presented in DNRM (2000), DNRM (2018) and DES (2018) are all based on the DNRM (2000) model and in our view, represent one of the many possible solutions in terms of a combination of recharge, extraction and groundwater heads, that 'calibrate' to the observed groundwater heads*."

3. **seriously questions the estimated quantities and extent of supplemented benefit that the schemes actually deliver in providing recharge to the groundwater aquifer of the Central Lockyer**.

   Whilst it is acknowledged that some irrigators occasionally receive tangible and valuable benefit from supplementation of the groundwater from the scheme, LWUF believe that the actual quantum and spatial/temporal benefit deserves revision. For example, LWUF notes that:

   a) overall, there have been minimal releases from the schemes due to their being at very low levels for the majority of time since their original commissioning

   b) with Lake Clarendon supplying the Moretonvale pipeline, there appears to be little residual water available to release to the creek for underground recharge

   c) Bill Gunn Dam is a gravity-fed scheme that only receives inflows during major flood events which are infrequent and of short duration in nature

   d) comparison of the volumes of releases from the schemes with the volume of Central Lockyer surface water licences (which both equate to around 5000 ML) indicate that there are generally minimal releases remaining for groundwater recharge.

4. **refutes the omission of water quality as being integral to the definition of benefitted groundwater**.

   LWUF regard water quality as a key determinant to defining whether groundwater is fit for purpose for irrigation and whether a bore should be categorised as being connected to benefitted groundwater or not. Irrigators and agronomists consider groundwater that has salinity levels of greater than 1000 ppm to be unsuitable for long-term sustainable farming of vegetables (other than salt tolerant crops such as beetroot). Accordingly, LWUF contend that bores exhibiting salinities worse than this should be automatically excluded from the benefitted area. In addition, there is no justification for the recent additional of a couple of new properties into the existing benefitted area.

5. **nevertheless, recognises and understands the value that a sensible and locally formulated water plan could bring to the benefitted area in the Central Lockyer.**

   This is, of course, on the proviso that a water plan for the benefitted area in the Central Lockyer be developed and implemented in close liaison with irrigators and based on sound science that is underpinned with valid data and a well-considered, contemporary conceptual groundwater modelling framework.

   The LWUF believe that a properly-prepared water plan for the Central Lockyer should:

   a) underpin sensible, practical and equitable water management arrangements in the Central Lockyer that reflects the natural seasonal variability of water supplies in the region and appropriately segregates the management of supplemented and natural-resource groundwater in the benefitted area

b) prepare the foundation for the introduction of new water sources delivered direct to farms.

6. **recognises the importance of robust water metering and groundwater level monitoring in the Central Lockyer.**

   LWUF believe that such a policy platform is critical to:

   a) enable the gathering of reliable and valid water data

   b) confidently design and build an accurate hydrologic model

   c) to support sustainable water management arrangements in the Central Lockyer.

7. **strongly views the introduction of part A fixed cost recovery for groundwater in the Central Lockyer schemes as being unjustifiable and inappropriate.**

   In view of the issues outlined above, we contend that the current volumetric pricing arrangements should continue.

8. **proposes a number of key principles to protect property values from being undermined, support businesses within the region and contribute to a water plan that is appropriate for the Central Lockyer.**

   These include:

   a) all properties in the benefitted area should be granted groundwater allocations with:

      i. nominal volumes set at the same ML/hectare applied to the total area of each property

      ii. a case-by-case consideration of situations where a landholder can prove their joint-management and utilisation of water entitlements across multiple lots (that may be located within and/or outside of the benefited area) in a way that is consistent with managing and utilising them as a single landholding

   b) seasonal adjustments/announced allocations (sharing rules) should be the mechanism for applying seasonal volumetric limits (i.e. not nominal volumes) for ensuring available groundwater resources are shared equitably between water users (differentiated at a sub-catchment/area level). These sharing rules should be transparent and be developed and administered in close consultation with irrigators (through the LWUF or other representative body)

   c) seasonal water assignments (temporary water trading) should be the mechanism to allow and enable water users to:

      i. move groundwater within sub-catchment/areas and/or surface water within surface water management zones

      ii. temporarily substitute surface water for groundwater (and vice versa) where sub-catchment/areas and surface water management zones interconnect. This would be important in scenarios where a surface water pump has been washed away and/or is not usable, or where groundwater user is unable to access surface water

   d) permanent and temporary water markets – rather than government policy interventions such as applying differential groundwater allocations – should be the mechanism to enable and drive micro-economic reform within the area

e) permanent trading should be allowed subject to trading rules to be determined (as part of the development if a new water plan) in close liaison with local irrigators and informed by the revised data and modelling

f) Provision should be made to allow carry-over and forward draw of seasonally available water to enable water supply risk to be managed between consecutive water years

g) The water year in the Central Lockyer should be changed from a financial year to a calendar year basis to better align the water management and sharing rules with the annual production planning and decision-making cycle

h) water sharing and water trading should be supported by a transparent water accounting system with management rules that reflect and/or are consistent with the rebuilt groundwater hydrology model

i) The intention to adopt the above principles should be communicated to water users at the commencement of the renewed planning process (but not implemented until the data and modelling fixes outlined below are complete).

9. **concludes that the government must set aside the current water plan amendment and embark afresh on a process by which irrigators and government openly and collaboratively formulate a new draft amendment.**

   Whilst LWUF acknowledge the cooperativeness of the department and the transparency of the current consultation process, the LWUF nevertheless contend that government has no option but to set aside the current water plan amendment and to start afresh on a new draft amendment for the Central Lockyer because:

- the water metering data is invalid – despite the majority of water meters within the area not being functional for an extended period of time, individual irrigators are able to show records (e.g. power and production records) that clearly indicate that their water usage has been substantially greater (on average between 80% to 100 % more) than that which has been assumed in the department's modelling (noting that some individuals are able to substantiate more than five time than this again in recent years)

- the current groundwater model is fundamentally flawed and does not meet current industry standards for a groundwater allocation and management tool – the department's groundwater hydrology model has been assessed as not complying with the requirements of the Australian Groundwater Modelling Guidelines (which are widely used in Australia by both modellers and reviewers to assess if a model is fit for purpose, particularly for regulatory approval purposes)[2]. This suggests that the government has no option but to instigate the model's urgent replacement prior to proceeding with defining groundwater allocations.

- the current draft plan proposals would result in catastrophic, unwarranted and unnecessary impact on individual agri-businesses, property values and the economy of the region.

To formulate a new plan, LWUF propose a process that includes the following elements:

a) adoption of the principles set out in point 8 above

b) establish an independent organisation (e.g. WaterCo Pty Ltd) that represents the interests of water users in overseeing the development and implementation of the new water plan and sustainable water management in the Central Lockyer

c) establish an agreed project plan (strategies, actions, milestones, KPIs, responsibilities, and funding sources) for developing and implementing a new water plan for the Central Lockyer

d) commit to urgently fix metering equipment and groundwater bores – noting that LWUF contend that irrigators should install, own and maintain the equipment (to agreed specification and standards) – LWUF's preliminary estimate suggests that this might total around $5m assuming 500 measurement sites (i.e.

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[2] See p35-41 of *Report on High-level Review of the Central Lockyer Groundwater Model*, hydrogeologist.com.au, January 2019.

extraction meters and monitoring bores)

e) develop and implement a water compliance management plan with government (including state and commonwealth government) that establishes:

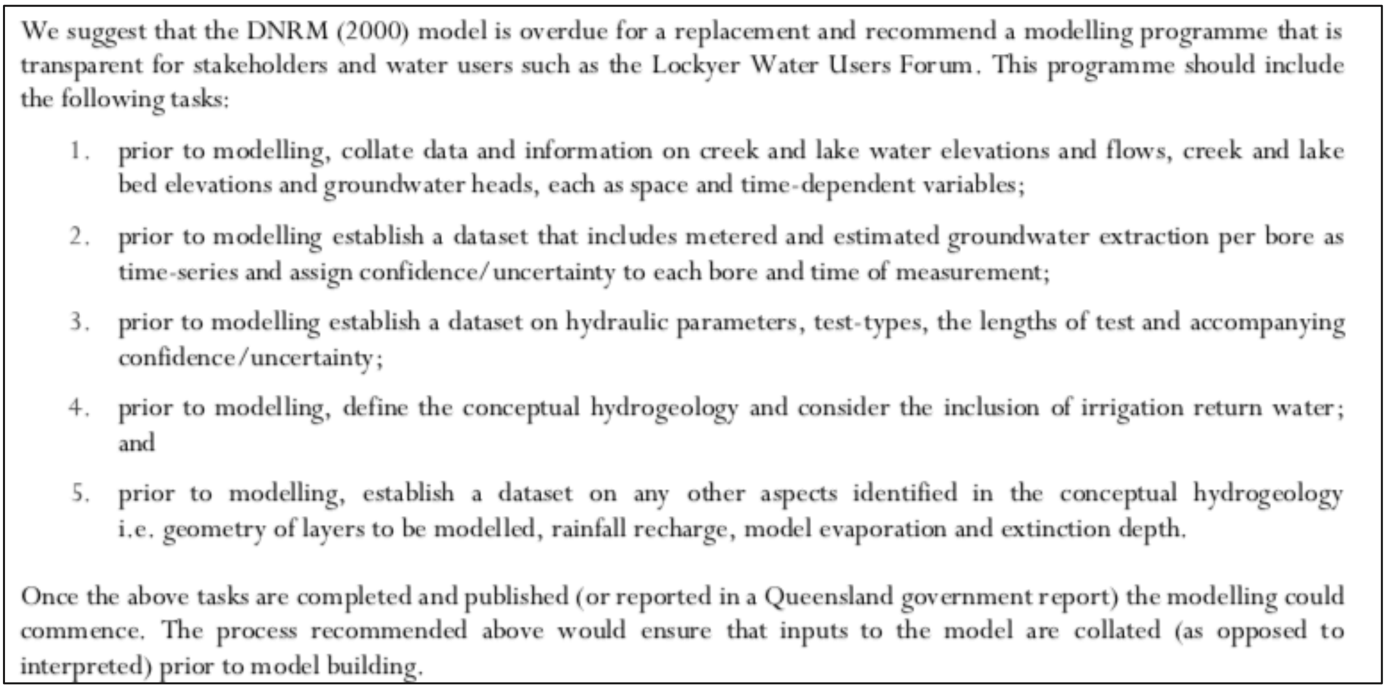
    i. actions, milestones, KPIs, responsibilities, and funding sources

    ii. framework for implementing self-managed telemetry that facilitates automated and coordinated reading of meters and monitoring of groundwater levels

    iii. systems for making sub-catchment water data transparent (including being shared with government as partners) to achieve improved water management

    iv. framework for government auditing of sub-catchment and individual metering data

f) rebuild the groundwater model (based on the hydrogeologist.com.au's recommendations and meeting the requirements of the national guidelines discussed earlier). LWUF wholly endorse the technical approach recommended by hydrogeologist.com.au (reproduced below from Section 5.4 of their report):



We suggest that the DNRM (2000) model is overdue for a replacement and recommend a modelling programme that is transparent for stakeholders and water users such as the Lockyer Water Users Forum. This programme should include the following tasks:

1. prior to modelling, collate data and information on creek and lake water elevations and flows, creek and lake bed elevations and groundwater heads, each as space and time-dependent variables;
2. prior to modelling establish a dataset that includes metered and estimated groundwater extraction per bore as time-series and assign confidence/uncertainty to each bore and time of measurement;
3. prior to modelling establish a dataset on hydraulic parameters, test-types, the lengths of test and accompanying confidence/uncertainty;
4. prior to modelling, define the conceptual hydrogeology and consider the inclusion of irrigation return water; and
5. prior to modelling, establish a dataset on any other aspects identified in the conceptual hydrogeology i.e. geometry of layers to be modelled, rainfall recharge, model evaporation and extinction depth.

Once the above tasks are completed and published (or reported in a Queensland government report) the modelling could commence. The process recommended above would ensure that inputs to the model are collated (as opposed to interpreted) prior to model building.

This will require:

    i. design and testing overseen by the WaterCo in liaison with government

    ii. development and delivery of the model by independent qualified hydrologists

g) build, adopt and implement a new water plan

10. Seeks support of local, state and federal governments for the above approach in working with irrigators to build and implement a better water plan for the Central Lockyer.

Proposed project plan and timeframes for rebuilding

The LWUF recognise that the above proposals will mean that developing and completing a water plan for the Central Lockyer will take more time. However, LWUF contend that the seriousness of the flaws in the current data and modelling approach warrant additional time and effort to "get it right".

LWUF are also keen to ensure that the water planning process is progressed and brought to a close in as timely a way as possible. To this end, the LWUF propose the following tentative project plan timelines:

A. Sign off by government(s) of revised water plan approach and timeframe – by end April 2019

B. Secure in-principle commitment for funding for metering/telemetry – by end April 2019

C. Establish WaterCo irrigator vehicle/entity – by end May 2019

D. Develop scope/timeline and agreement – by end May 2019

E. Secure funding for metering/telemetry – by end June 2019

F. Develop specifications for metering and monitoring of Central Lockyer – by end July 2019

G. Call for tenders for metering/telemetry hardware and data processing software platform – by end October 2019

H. Review tenders and announce successful tenderer – by end November 2019

I. Install, test and implement metering and monitoring hardware and software system – through 2020, full go-live by end 2020

J. Procure and build conceptual new groundwater model – through 2020

K. Calibrate and validate new groundwater model – through 2021/22 (weather dependent)

L. Develop – and release for public review and consultations – draft water plan rules for establishing groundwater allocations and water management rules (trading rules, water sharing rules, carry-over etc) for the Central Lockyer benefitted groundwater area – early 2023

M. Finalise and implement new water plan – by end June 2023

Our commitment to sound water management

We, the irrigators of the Lockyer Valley, commit to working with the government through LWUF and/or a WaterCo to develop and establish a sensible, locally-led and scientifically-valid water management plan that:

- is customised for, and reflects the unique needs and nature of the Central Lockyer
- continues to maintain the direct and indirect viability of individual farming enterprises and local business servicing agriculture and
- ultimately underpins the prosperity of the region and community as a whole.

Signed______ 1st February 2019
CHAIRMAN LWUF
For the Lockyer Water Users Forum Incorporated

Attachments to Submission

Report on High-level Review of the Central Lockyer Groundwater Model, hydrogeologist.com.au, January 2019.

Register of support for the LWUF's Submission hydrogeologist.com.au

REPORT ON

High-level Review of the Central Lockyer Groundwater Model

FOR

Lockyer Water Users Forum Associated Incorporated

23 January 2019

www.hydrogeologist.com.au ABN: 50 627 068 866 info@hydrogeologist.com.au
1/149 Boundary Road, Bardon. QLD. 4065 P.O. Box 108, The Gap. QLD. 4061

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High-level Review of the Central Lockyer Groundwater Model

Prepared for

Lockyer Water Users Forum Associated Incorporated

1. Introduction

hydrogeologist.com.au have been commissioned by the Lockyer Water Users Forum to provide a high-level review (the 'Review') of the Central Lockyer Groundwater Model (the 'Model'). The objectives, scope and proposed methodology were presented in our proposal of 19 November 2018. Our proposal was based on our understanding of the Terms of Reference (ToR) provided by Badu Advisory Pty Ltd (email of 14 November 2018), and our subsequent email correspondence.

1.1. Objectives and scope

The background to the Review is provided in the ToR and is not repeated here. The objective is a high-level review of documents related to the Model with focus on the following issues:

- Is the Model fit for the purpose of groundwater allocation and management?
- The confidence in modelling outputs, uncertainties and/or limitations in modelling data inputs, assumptions, model set-up and overall technical approach.
- Key issues and factors relevant to the hydrologic performance of the Central Lockyer groundwater system.
- Responses to irrigators' views, concerns, insights and questions in relation to the above.

hydrogeologist.com.au understand the scope, provided in the ToR, includes the following:

1. Obtain a copy of the department's Central Lockyer Groundwater Model (MODFLOW), and associated Documentation, data, model runs, output data relevant to the draft plan and relevant Model Licence agreements from DES necessary to conduct this Review.
2. Participate in an initial workshop in Gatton with representatives of Lockyer irrigators, facilitated by the Strategic Advisor (Badu Advisory Pty Ltd).
3. Undertake detailed review and assessments – and the field investigations option if/as agreed and prepare the draft report.
4. Participate in a second workshop in Gatton with representatives from Lockyer irrigators, facilitated by the Strategic Advisor.
5. Finalise the report addressing the objectives including irrigator feedback on the draft report.

1.2. Reports reviewed

A significant number of reports and data were made available to **hydrogeologist.com.au**, however only the following reports were reviewed as part of this scope of work:

- DNRM, Department of Natural Resources & Mines. (2000). Central Lockyer Groundwater Model. Groundwater Model Report. Water Assessment NRS – RC&T Natural Resource Sciences, 80 Meiers Rd, Indooroopilly, Qld 4068. Department of Natural Resources & Mines.
- DNRM, Department of Natural Resources & Mines. (2018). Central Lockyer Valley water supply scheme benefitted groundwater area. Technical report for the Moreton Water Plan amendment, November 2018. Water Services South Region, Department of Natural Resources and Mines. © State of Queensland, 2018.
- DES, Department of Environment and Science. (2018). Central Lockyer groundwater model scenario. Prepared for Department of Natural Resources, Mines and Energy. Queensland Hydrology, Water Planning and Coastal Sciences, Science Delivery Division, Department of Environment and Science, GPO Box 2454, Brisbane QLD 4001, © The State of Queensland (Department of Environment and Science) 2018. Draft report, version 2 dated 06/12/2018.

1.3. Methodology and the structure of this report

The three reports above were reviewed with focus on achieving the objectives and answering the Lockyer Water Users Forum's questions. In reviewing DNRM (2000), some of the comments refer to the model development. At the time of the DNRM (2000) model development (through the 1990s), software and hardware were inferior to those available at present. However, we provide our comments as if the model was created recently as we understand that the proposed water allocation in the Central Lockyer Valley is based on DNRM (2000).

In Section 2 through to Section 4, we provide a summary of the important issues identified through this review for each of DNRM (2000), DNRM (2018) and DES (2018), respectively. Section 5 contains our conclusions and recommendations, including our summary responses to the questions raised by the Lockyer Water Users Forum.

Appendix A is a presentation delivered to the Lockyer Water Users Forum on the 18 January 2019. The presentation is based on the findings of this report.

1.4. The Central Lockyer Valley Water Supply Scheme

This summary of the Central Lockyer Valley Water Supply Scheme (CLVWSS) is based on DNRM (2018).

The CLVWSS, located near Gatton in southeast Queensland, was established in the 1980s and is currently operated by SEQWater. The CLVWSS comprises two off-stream storages, Lake Clarendon near Gatton and Lake Dyer (also called Bill Gunn Dam) near Laidley, and several weirs that together function as infrastructure to support agriculture in the Central Lockyer Valley (Figure 1.1).

The off-stream storages were established as opportunistic dams for the diversion and storage of water during high flow events. Releases to the Lockyer Creek and Laidley Creek are made from both lakes as storage allows.

The CLVWSS consists of:

- groundwater in alluvial aquifers where recharge is augmented by natural flows within Lockyer Creek and Laidley Creek, the water released from Lake Clarendon and Lake Dyer via Lockyer and Laidley Creeks, and a series of instream weirs to improve groundwater recharge (the 'benefitted groundwater');
- surface water supplied to users from Lake Clarendon and Lake Dyer via Lockyer and Laidley Creeks; and
- surface water supplied to water users via the Morton Vale pipeline from Lake Clarendon.

1.4.1. Releases from Lake Dyer and Lake Clarendon

Lake Dyer was constructed in 1987. Water is released from Lake Dyer to the Showgrounds Weir on Laidley Creek and flows continue down Laidley Creek to its junction with Lockyer Creek at the Glenore Grove Weir and beyond to the Kentville Weir on Lockyer Creek. The first releases from Lake Dyer were made in 1988. In 1991, the benefitted groundwater area was set based on an understanding at that time of enhanced groundwater recharge from releases from Lake Dyer down Laidley Creek and into Lockyer Creek.

In 1992 Lake Clarendon was constructed. Water is released from Lake Clarendon into Jordan Weir and Jordan 2 Weirs, the water then flows down Lockyer Creek via Wilsons Weir, Clarendon Weir and Glenore Grove Weir to Kentville Weir. The first water was released from Lake Clarendon in February 1996. In 1997, the benefitted groundwater area was expanded to include that area that would benefit from releases from Lake Clarendon into Lockyer Creek.

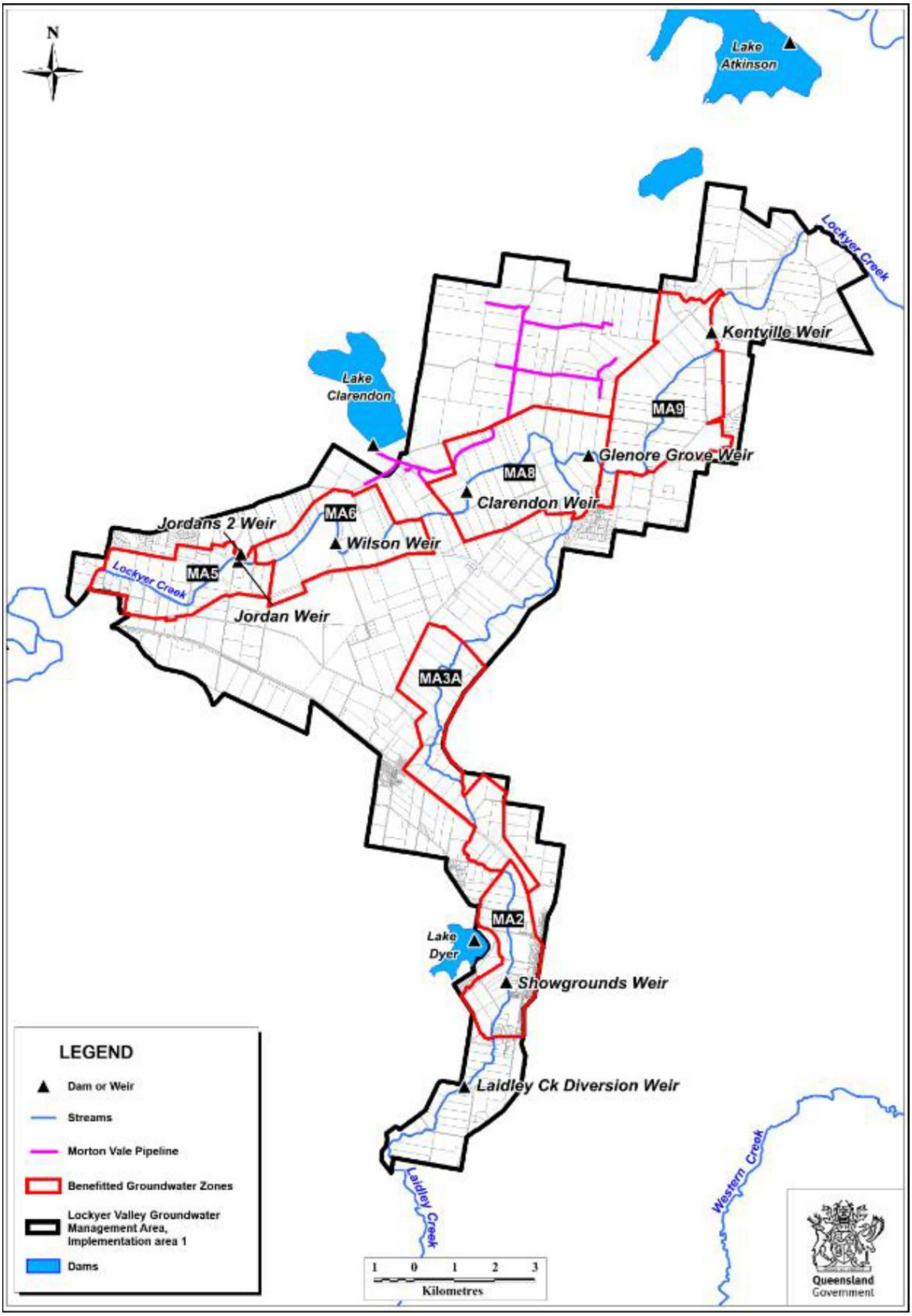


Figure 1.1 The current CLVWSS benefitted area (after DNRM, 2018)

2. Review of DNRM (2000)

2.1. Summary

The DNRM completed a modelling report for the Central Lockyer Groundwater Model in 2000. The model was created to:

"simulate aquifer responses to recharge and groundwater extraction, and to then be used as a tool in the decision making process regarding the setting of groundwater allocations".

The modelling software used were MODFLOW 88, PMWIN 4 and PEST. The model simulation period is from July 1987 to July 1997. The model domain consists of 15,000 200 m by 200 m cells, of which 3,214 cells are active (Figure 2.1).

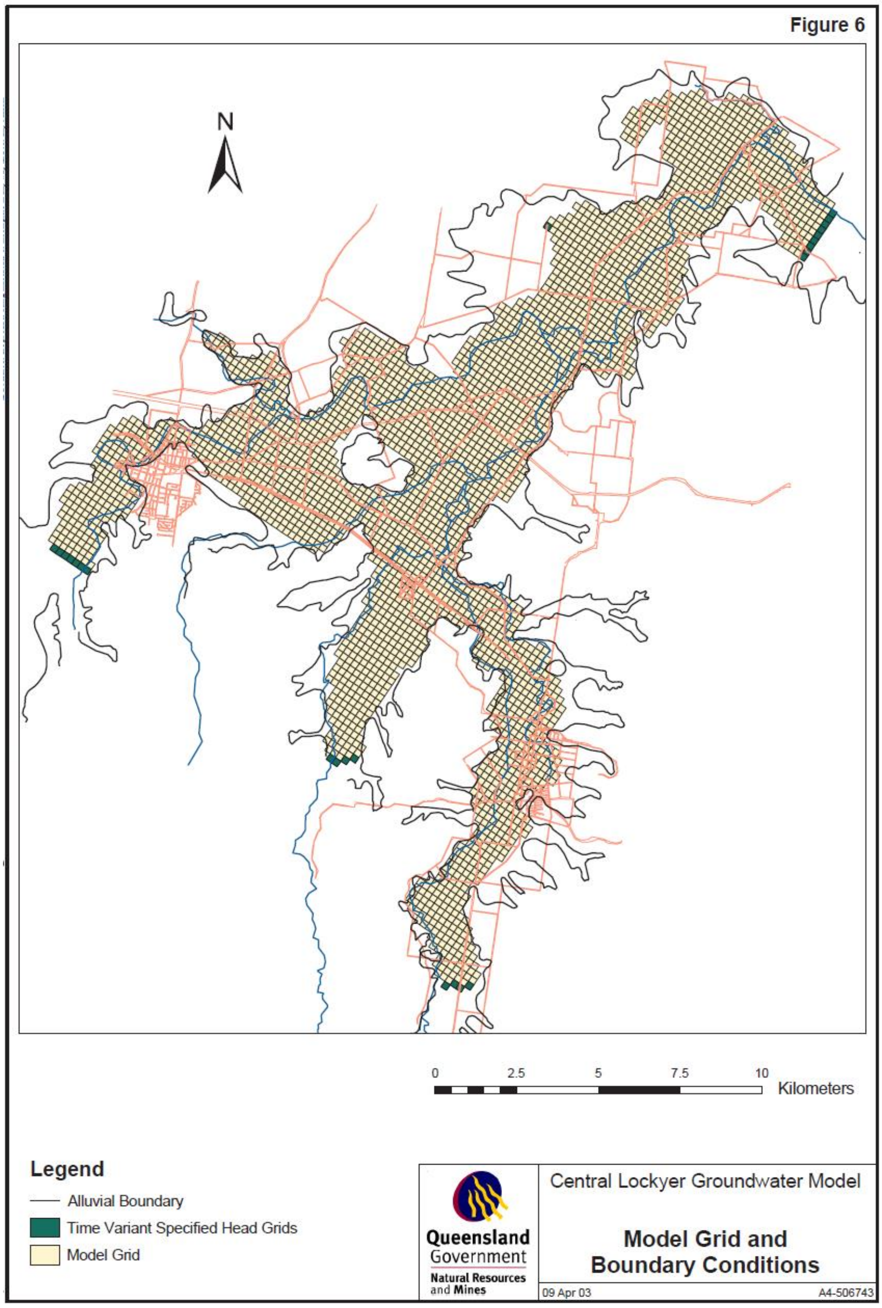


Figure 2.1 Model area and boundary conditions (after DNRM, 2000)

The model consists of a single layer, representing the sand and gravel component of the alluvial aquifer. This aquifer is defined by its base and top, the latter in places with some adjustment to increase the thickness to avoid unrealistic model calibration. The aquifer is of variable type, i.e. can vary between unconfined and confined depending on the position of the groundwater head.

The model boundary conditions represented by DNRM (2000) are understood to be:

- RECHARGE cells to simulate recharge from surface water;
- WEL cells to simulate groundwater extraction; and
- time-variant fixed head cells to simulate lateral in- and outflow to/from the model.

The calibration targets were groundwater elevations from 103 DNRM monitoring bores.

Modelling was completed in three stages:

- STAGE 1 – 18/04/1993 to 29/9/1995, generation of aquifer parameters;
- STAGE 2 – 29/09/1995 to 30/06/1997, generation of recharge locations and maximum recharge rates; and
- STAGE 3 – 01/07/1987 to 18/04/1993, estimation of historical recharge volumes.

Sensitivity analysis was provided by modifying the hydraulic parameters by ±20%.

Model calibration errors were reported around 1 m which indicates a reasonable fit between observed and modelled groundwater heads. The water balances for each of the three stages indicate the most dominant factors are groundwater extraction (all stages), recharge from surface water (Stages 2 and 3) and changes in storage (Stages 1 and 2). Overall, the dominant factors for the entire model response are groundwater extraction and recharge from surface water.

No analysis was provided for the uncertainty in the dominant factors, groundwater extraction and recharge from surface water.

2.2. Important issues identified by the review

There are three major issues identified through our review of DNRM (2000):

- lack of transparency in model documentation and in model building;
- incomplete conceptual hydrogeology; and
- the simplistic conceptualisation of surface – groundwater interaction.

2.2.1. Lack of transparency in model documentation and in model building

The lack of transparency in model documentation and in model building appears to affect the entire documentation. There is a general absence of data and facts and referencing the presumably large amount of work that has been completed prior to the modelling. There are only three publications listed in the references section, two of which refer to modelling software.

There is an absence of data and information known prior to the model construction relating to rainfall recharge, hydraulic parameters, published quantitative evidence for surface water – groundwater interaction; and the analysis of groundwater flow in both the horizontal and vertical sense (with the exception of groundwater head maps at selected times aiding the setting of fixed-head boundary cells). Due to the absence of the data, the conceptual hydrogeology and the model are built on concepts that may or may not be correct/plausible, and there is little information presented or referenced to make a balanced judgment.

2.2.2. Incomplete conceptual hydrogeology

The conceptualisation of hydrogeology is presented by DNRM (2000) in a section entitled “5.2 Model Conceptualisation”. In reality, this section appears to be a mix of hydrogeological conceptualisation and model development. This, in our experience, is not good practise. Good modelling practise (Barnett *et al.*, 2012) suggests a section on hydrogeological conceptualisation, followed by a description of model building, i.e. how the concepts were adopted in the model.

The system was conceptualised as a single layer system with no rainfall recharge or evaporation. Recharge from surface water to groundwater was conceptualised, but apart from several geological cross-sections, no data or information on recharge rates independent of the model were presented or referenced. No hydraulic parameters (for example from pumping tests) were presented; neither was an analysis of groundwater flow in both the horizontal and vertical sense provided. Although the inclusion of irrigation return water (and rainfall recharge) to the model were briefly discussed, their inclusion was dismissed on qualitative grounds only (Section 5.2.3.2).

The exclusion of the above features is important not just because the model report does not provide an adequate conceptual hydrogeology, but the features above may not subsequently be correctly translated to the model or not represented at all. The exclusion of underlying sandstones from the model and the use of a single-layer model, for example, appears to be driven by the lack of data and information (pages 20-21) not by sound concepts. The geological cross-sections presented in Figure 5a to 5d, if augmented by groundwater and surface water heads (or ranges of those), may have shown in places, such as beneath Lockyer Creek on Figure 5c, the potential for interaction between the creek, alluvium and the underlying sandstone. There appears to be potential for rainfall recharge of the sandstones in the margins of all cross-sections and, in particular, beneath the sandstone hill covered by sands in Figure 5d. In addition, DNRM (2000) assumed that recharge occurs from surface water to groundwater at all stress periods and reaches of the creeks. In our experience, the interaction between surface and groundwater is complex and often dynamic; also often adjoining reaches may recharge and receive groundwater at a given time, this concept of complex interaction does not appear to have been represented in the numerical model.

As a one-layer model was adopted, the sediments between the sand and gravel alluvium and the land surface, are not presented and therefore the represented surface watercourses would ‘float’ above the model, i.e. the watercourses cannot be simulated by the RIVER package in the one-layer model adopted by DNRM (2000). The resultant simulation of surface water recharge to groundwater is calculated outside the model and is not transparent.

The absence of hydraulic data prior to modelling suggests that realistic parameter constraints or bounds have not been established and hydraulic parameters had to be estimated from the model calibration in Stage 1. The effects can be seen in Figure 15 that indicates the existence of zones with straight, unnatural looking boundaries and some zones with a huge contrast in adjoining hydraulic conductivity, that is 250 m/day vs 5 m/day, and 143 m/day vs 3 m/day. It is difficult to comprehend how such an alluvial system has developed and how these contrasts, which appear to be the result of model error minimisation, can be justified.

Ultimately, the incomplete conceptual model means an incomplete numerical model. It is important to note that although the model calibration errors are small, around 1 m root mean square (RMS), the model solution provided is based on a water balance that appears to be overwhelmingly dominated for the 1987 to 1997 period by surface water recharge and groundwater extraction. The sensitivity analysis provided for each stage involves varying the hydraulic parameters only and no uncertainty analysis is offered. In our view, if recharge and/or extraction were modified, they would have generated a different set of ‘calibrated’ hydraulic parameters, with a likely similar RMS error to those presented in DNRM (2000).

2.2.3. The simplistic representation of surface -groundwater interaction in the model

In our opinion, a description of surface water – groundwater interaction is missing from DNRM (2000). A comprehensive description of surface water – groundwater interaction should have been included, especially the following aspects:

- groundwater – surface water interaction is dynamic and is likely to vary with time and space;
- recharge is time-dependent;
- recharge depends on both surface water and groundwater heads;
- recharge depends on the surface water head above the river bed if the groundwater head is below the river bed bottom; and
- recharge depends on groundwater head if that is above the river bed.

DNRM (2000) assumed that recharge occurs from surface water to groundwater at all stress periods and reaches of the creeks. In our experience, the interaction between surface and groundwater is complex and often dynamic; also often adjoining reaches may recharge and discharge groundwater at a given time. This concept should have been explained in DNRM (2000) together with a justification as to why the surface recharge was not modelled using the RIVER package.

We also believe that, because a one-layer model was adopted, the sediments, between the sand and gravel alluvium and the land surface, are not represented at all and therefore the surface watercourses would ‘float’ above the model surface. The resultant simulation of surface water recharge to groundwater by recharge cells is calculated outside the model and is not transparent. For surface water – groundwater interaction, a set of simultaneous flow measurements along the river (or surface water balances) should have been provided and these would have guided eventual model calibration (page 36 of DNRM, 2000 refers to such measurements but only provides a tabular summary of recharges for each stress period without explaining how the calculations were made or a reference to a report.

In our experience, the best and most transparent way of simulating surface – groundwater interaction is by using either the RIVER (or STREAM) package. If the RIVER package was used, for example, the variables required would have been the elevation of surface and groundwater heads, and a river bed conductance (hydraulic conductivity and thickness of the riverbed) for each stress period. Of these, the elevation of surface and groundwater would be expected to be measured (and available), and the riverbed conductance is often applied as a calibration target to achieve a fit to the calculated recharge. The latter would normally be calculated from simultaneous flow measurements along the river or from surface water balances. Using this above approach, recharge for each cell, and for each stress period would have been calculated internally by the model in a transparent way. Such method, if followed, would have avoided conflicting statements such as those provided on pages 33 and 35 of DNRM (2000):

Although the period of April 1993 to September 1995 was chosen for its lack of recharge, there was still recharge of quantifiable levels, and as such they need to be included in the model for completeness. (page 33)

As there was little to no recharge in the model domain during this period, recharge ceases to be an unknown in the model, and the aquifer material parameters (hydraulic conductivity and storativity) can be ‘reliably’ calibrated, as they are conceptually the only unknowns.(page 35)

The statements provided by DNRM (2000) on pages 33 and 35 (reproduced above) appear to be in direct conflict. We suggest that the best and most transparent way for modelling groundwater-surface water interaction is inside the model using the RIVER package. Importing time-series recharge values from outside the model without a proper discussion on how they were estimated is, in our opinion, not adequate for a model on which water allocation will be based.

2.2.4. Detailed extracts and comments

Extracts are indented and in *italics* and within a text box, our comments (where applicable) are in non-italics and outside of the text box. All are referenced to page numbers associated with DNRM (2000).

Page 8.

> *Modelling the Central Lockyer Valley aquifer system has been achieved in three stages. Firstly, calibration of the aquifer parameters was done to allow the model to replicate historical water level response. Secondly, estimation and calibration of recharge locations along the creeks and major drainage lines were undertaken with the aquifer parameters held constant. Thirdly, the recharge locations resulting from Stage 2 were used to calibrate recharge over a long period. Testing the model was then done with scenarios allowing variations in areal allocation volumes and release (recharge) options over a historical period of observation.*
>
> *A period from 1987 to 1997 was chosen to focus the modelling exercise on. Data was examined from other periods, however the model (when the stages are combined) simulates groundwater flow during the ten-year period from 1987 to 1997. This ten-year period was selected because of the abundance of accurate metered water use and groundwater level data available. The average rainfall for this ten-year period is similar to the long-term average rainfall.*

A somewhat unusual way of building a groundwater model was employed because of the necessity of identifying and assessing surface water recharge to groundwater.

Page 9

> *The groundwater storage of concern to this project is the alluvial aquifer of the Lockyer Valley, due to it being the main source of irrigation water in the area. The alluvial boundary is shown in Figure 2 with the corresponding satellite image. This aquifer overlies a sandstone aquifer that does contain water, however it doesn't produce it at the same rate of the alluvial sediments, and certainly not to the volumes required for irrigation purposes.*

Page 12

> *An artificial recharge scheme has been developed for the model area (proclaimed area). This scheme involves two major off-stream storages (Lake Dyer and Lake Clarendon – shown in Figure 3) and a series of recharge weirs along Lockyer and Laidley Creeks. The methods behind the scheme are the harvesting and off stream storage of water from the creeks during periods of high flow. This water is then released at a later stage back to the creeks for groundwater recharge and riparian surface water use.*

Page 13

> *To achieve the project objectives the modelling exercise is divided into 3 stages or steps. The three stages are:*
>
> *STAGE 1 – 18/04/1993 to 29/9/1995, generation of aquifer parameters,*
>
> *STAGE 2 – 29/09/1995 to 30/06/1997, generation of recharge locations and maximum recharge rates*
>
> *STAGE 3 – 01/07/1987 to 18/04/1993, estimation of historical recharge volumes.*

Pages 14-16

> *MODFLOW 88, PMWIN 4 and PEST were used.*

Pages 20-27

The section entitled “5.2 Model Conceptualisation” appears to be a mix of hydrogeological conceptualisation and model building. This, in our experience, is not a good practise. Good modelling practise suggest a section on hydrogeological conceptualisation, followed by a description of model building, i.e. how the concepts were adopted in the model.

As a result, important features of conceptual hydrogeology are excluded from section 5.2:

- the discussion of hydrostratigraphy /justification for using a one-layer concept;
- rainfall recharge;
- evaporation;
- quantitative evidence for surface water – groundwater interaction;
- hydraulic parameters; and
- analysis of groundwater flow in both the horizontal and vertical sense.

The exclusion of the above features is important not just because the model report does not provide an adequate conceptual hydrogeology, but the features above may not subsequently be correctly translated to the model or not represented at all.

Using the example of hydraulic parameters, a summary of pump tests and their interpretation to hydraulic parameters (such as hydraulic conductivity and specific yield or specific storage) should have been provided and these should have guided zonation within the model build.

For surface water – groundwater interaction, for example, a set of simultaneous flow measurements along the river or surface water balances should have been provided and these would have guided eventual model calibration (page 36 of DNRM, 2000 refers to such measurements but only provides a tabular summary of recharges for each stress period without explaining how the calculations were made or a reference to a report). In addition, DNRM (2000) assumed that recharge occurs from surface water to groundwater at all stress periods and reaches of the creeks. In our experience, the interaction between surface and groundwater is complex and often dynamic; also often adjoining reaches may recharge and receive groundwater at a given time.

DNRM (2000) is silent on all the above aspects, although it provides a series of geological cross-sections in an attempt to justify the adoption of a one-layer model.

Page 22

> *The cross-sections show an aquifer that is covered in most parts by clay or at least a clayey material. While the clay material is still considered alluvial and stores water, it cannot be considered aquifer as it has very little ability to transmit water. When water levels reach the bottom of the clay layer they are effectively held at that point. The potentiometric head is still allowed to rise due to an increase in pressure, however the water is effectively confined to the elevation. When the water is under pressure it takes on different storage properties to when it is unconfined with a phreatic surface, and hence this must be accounted for in the modelling process.*
>
> *The results of the conceptualisation point to a 1-layer model. The conceptualisation also points to this one layer acting as both a confined and unconfined aquifer.*

This one-layer conceptualisation ignores the underlying sandstone aquifer (Page 9) and limits the modelling in terms of what packages can or cannot be used. For example, the RIVER and EVAPORATION packages may not directly be used as topography is not explicitly modelled. With hindsight, a three-layer model (clay, alluvium and sandstone) would have been more transparent and less restrictive in our opinion.

Further, the cross-sections in Figures 5a to 5d could have been improved by plotting groundwater heads, river heads (or ranges for both) and heads available for the sandstone. Additional comments:

- In places, such as beneath Lockyer Creek on Figure 5c, the potential for interaction between the creek and the sandstone exists.
- There appears to be a potential for rainfall recharge of the sandstones in the margins of all cross-sections and, in particular, beneath the sandstone hill covered by sands in Figure 5d.
- DNRM (2000) suggest that the overlying clays do not allow significant rainfall recharge to enter the alluvial groundwater system. On the cross sections, however, loam, sandy loam, sandy clay, sand and sandy soil are all noted in the clays. These will, in general, allow water movement. In addition, the black soils and clays may shrink and crack when dry, providing preferential flowpaths for subsequent rains.

Pages 23-24

> *There were also discussions of the inclusion of the sandstone aquifer below the alluvium – modelled as another layer. Again there is a problem of not enough discrete observational data for this layer. The other issue that stopped this idea was the lack of understanding of the interactions between the alluvial and sandstone aquifers. From the evidence of water level reactions to recharge events, it seems that most of the water entering this system is through the creeks, and it is thought that there is little input from the sandstone bottom.*

Appears to suggest that modelling drove the conceptualisation; contrary to good modelling practise in which hydrogeological conceptualisation is followed by developing a model (Barnett *et al.*, 2012).

The conclusion, based on groundwater level reactions to recharge events, that there is little input from the sandstone needs, in our opinion, further justification. The vertical flow between the aquifer and the sandstone may be small beneath the rivers/creeks in comparison to surface water recharge, but it may be significant elsewhere within the model domain. In our experience, the alluvial aquifer may recharge the sandstones away from the surface drainages and the opposite may occur at lower altitudes and beneath the surface watercourses. In addition, the clay layer above the aquifer would have the ability to store significant volumes of groundwater and transmit / leak water under increased gradients.

In terms of model water budget, vertical flows may be small per unit area but, because they act on most of the active model domain, they could be substantial over the entire model domain. At the least a semi-quantitative explanation of Darcian flow would be required comparing horizontal and vertical flows.

Pages 21-22

> *The alluvial aquifer is however continuous beyond this area extending to the Upper and Lower Lockyer Valley groundwater areas. These areas are connected to the focus area, and as such their interaction needs to be accounted for in the form of a boundary condition. At these locations the continuous aquifer has been 'cut off', therefore an allowance for the flow that should be entering or leaving the model across the boundary needs to be made. This is done through the definition of a boundary condition.*
>
> *There are 25 cells being utilised in the 'time variant specified head' package. The locations of these cells are shown in Figure 6.*
>
> *The boundary conditions, which mostly affect the flow and general movement of groundwater around the model domain, are the stresses on the system – the groundwater extraction from, and recharge to the aquifer system. These boundary conditions are often referred to as specified flow boundaries, where an amount of water (volume or depth) is added to the system.*

Pages 24-25

Groundwater extraction in the Central Lockyer Valley takes place primarily for the purpose of irrigation of cropping activities. Extraction increased dramatically with the supply of electricity to the valley in the 1930's and the introduction of the turbine pump in the 1950's.

During the period of available waterlevels for the area there have been 4 occasions where the waterlevels have fallen dangerously low. This is due to a combination of groundwater extraction with little to no recharge. The occasions that this has occurred are; - summer 1970 / 71, summer 1980 / 81, summer 1986 / 87 and in mid to late 1995.

The majority of the model area (referred to as the Clarendon Sub-Artesian Area) was proclaimed in 1988. As a follow on from this proclamation, all the irrigation production bores (excluding domestic and stock bores) were licensed and fitted with volumetric meters. The meters were used to monitor use for future management purposes and levee charges for groundwater use, where bores were considered to benefit from artificial recharge activities (see section 5.2.3.2.1).

The installation of meters began in 1989 and continued until 1992 when the vast majority of bores had been metered. In terms of groundwater modelling, the existence of metered data is exceptional, as this is often an unknown and must be estimated from crop type and area being irrigated.

While the model area encompasses all of the Clarendon Sub-Artesian Area, it also encompasses areas outside this proclaimed area. These areas comprise the alluvial surrounds of the Clarendon Sub-Artesian Area and in particular the Sandy Creek alluvial area. These areas, being outside the proclaimed boundary, have not had meters installed on production bores, and thus require estimation of the groundwater extraction.

Figures from the metering of bores indicate that the Clarendon Sub-Artesian Area is responsible for between 15000 and 16000 ML of groundwater extraction per year.

Bores which are used for the purposes of stock and domestic use were not metered, and hence do not appear in the model. It is not known exactly how their inclusion would affect the model, although typical extraction rates would have minimal effect on the aquifer watertable levels at the regional scale.

Page 26

The majority of recharge in the model area occurs through the creek system. This is evident by the mapping of the waterlevel rise away from the creek after a recharge event. Incision of the creeks into the aquifer below allows for recharge to take place – as a thick clay layer covers most of the aquifer (see Figure 5 d). This incision is not continuous along the creek, thus different sections of the creek recharge different volumes.

Although there is likely to be some irrigation return flow to the aquifer on an areal basis, it is thought to be minimal due to the clay overlying the aquifer. In comparison to the recharge from creeks, the recharge through the soil profile is a very slow process and certainly not the major contributor to the waterlevel fluctuations experienced in the alluvial aquifer. After a rainfall event and subsequent recharge through the creeks, a 'wave' of watertable rise can be seen propagating outwards from the creek.

DNRM (2000) does not appear to use any rainfall recharge or evaporation in the model. Rainfall is described on page 9 as "…events are often of a short duration and high intensity, with the average rainfall between 750 and 800 mm per year. Summer dominance appears in the yearly rainfall distribution with around 70% of the yearly total falling between October and March".

An annual average rainfall of 750-800 mm would normally result in some groundwater recharge, depending on climate (rain, evaporation), soil and vegetation type and the depth to groundwater. Where the clay is discontinuous or thin, local runoff may penetrate the soils and eventually recharge groundwater.

Currently the recharge scheme involves the use of both water harvesting and ponding of creek flow to achieve additional recharge to the area. The water harvesting involves 2 major storages located in the model domain. Both storages have minimal catchment area above them, instead sourcing their water from the creeks during periods of high flow. The 2 storages being referred to here are Lake Dyer and Lake Clarendon (see Figure 3). The other components involved in the recharge scheme are various weirs placed along the creeks. The spacing of these weirs on Lockyer Creek is such that – when they are full they "back up" to the previous upstream weir.

Lake Dyer was completed in 1987 and the first releases were made in 1988. Lake Clarendon was completed in 1992 and harvested water for the first time in November 1995 allowing the first release of water in February 1996.

DNRM (2000) does not provide an explanation of how these storages are represented in the model. We assumed, based on Figures 13 and 19, that the weirs are represented by recharge cells and Lake Dyer and Lake Clarendon are not represented in the model (but the releases from them are). The lack of lake representation is probably an artefact of the one-layer model, i.e. the lakes are situated above the top of the model surface and therefore cannot be simulated by the RIVER package.

Page 28

Using a cell size of 200m x 200m and a rotation of 56^o of the grid axes it was found that 100 rows and 150 columns were required to cover the model area. Due to the 'fingery' and narrow nature of the alluvium only 3214 of the resulting 15000 model cells were designated active. The active model grid can be seen in Figure 6 – showing the grid rotation and the position of the model within the alluvial boundary.

Considering the importance of surface water recharge to groundwater, an analysis of the width of creeks and the dimensions of storages should have provided information on optimum cell sizing. The 200 m by 200 m grid appears to be too coarse. Page 36 appears to indicate this:

"Cells that contain large enough sections of the creeks were defined as recharge cells."

Current practise in modelling aims at matching the cell size to those of the objects (here creek width) and vary the grid so that it is fine where hydrogeological processes (surface – groundwater interaction) concentrate and it is coarse at the margins of the model. There has been significant advancement in recent years using unstructured grids within MODFLOW (USG) which would significantly improve the spatial representation of the surface water systems and alignment within the alluvial aquifer. MODFLOW USG is now more of a standard modelling package.

Page 29

Initially the strata logs were interpreted very stringently with only sand gravel and loams considered aquifer material. At a later stage it was found that the model was performing poorly and was calibrating to unrealistic parameter values. A reassessment of the aquifer material definitions (inclusion of the sandy clays) found that the model calibrated and performed much better.

Appears to suggest that modelling drove the conceptualisation; contrary to good modelling practise in which hydrogeological conceptualisation is followed by developing a model (Barnett *et al*., 2012).

Re-examination of the strata logs showed that there were reasons to include some of the loamy and clayey type of material that was previously not considered for definition as aquifer material. This was not discovered until after the model had been through initial calibrations, where parameter values were calibrating to unlikely extremes and groundwater extractions were causing excessive drawdowns.

In our view, not enough thickness to distribute water more likely to have been caused by adopting a one-layer model and excluding the underlying sandstone unit. The one-layer model effectively assumes the sandstone below (and the clay above) does not store or transmit significant water with respect to the alluvium.

The inclusion of sandstone appears more robust than the inclusion of loamy and clayey type material. DNRM (2000) does not provide a quantitative justification for the exclusion of the sandstone from the model. In our experience, the transmissivity of the sandstone should be less than 0.01 times that of the alluvium to justify such an exclusion.

Page 31

> *Recharge volumes are supplied to MODFLOW through arrays of cell values. The cell value supplied is a depth of recharge. The depth value is later converted to a volume internally within MODFLOW before calculations are done. The calculation involves the assumption that the recharge depth is applied over the entire area of the model cell.*

In our experience, the best and most transparent way of simulating surface – groundwater interaction is by using either the RIVER or STREAM package. DNRM (2000) is silent on important issues such as how much recharge is used and how it was calculated; also does recharge in the model change with time and surface- and groundwater elevations?

If the RIVER package was used, for example, the variables required would have been the elevation of surface and groundwater, and a river bed resistance (hydraulic conductivity and thickness of the riverbed). Of these, the elevation of surface and groundwater are typically known, and the riverbed resistance is normally a calibration target to achieve a fit to the calculated recharge. The latter would normally be calculated from simultaneous flow measurements along the river or from surface water balances.

Because a one-layer model was adopted, the clays, between the alluvium and the land surface, are not presented at all and therefore the surface watercourses would also 'float' above the model, i.e. cannot be used in the one-layer model adopted by DNRM (2000). The resultant simulation of surface water recharge to groundwater by recharge cells is calculated outside the model and is not transparent.

Pages 31-32

> *For the purposes of calibration, 103 observation bores were chosen. These bores were chosen on a number of criteria: -*
>
> - *Location*
> - *Aquifer intersection (where water is being measured from)– alluvial verses sandstone*
> - *Period of records*
> - *Frequency of records*
> - *Reliability of records*
>
> *The location of the observation bore is important in respect to calibration. It is important to have as 'even' a spread of bores as possible, such as to not bias any one part of the model. Figure 10 shows the distribution of the 103 observational bores used for the calibration. The same 103 bores were used for all 3 stages of the modelling exercise.*
>
> *Most of the 103 bores had adequate period of record for the required model runs. Where there was not enough record for the bore, observations were derived via examination of existing surrounding observations for that time. A relationship between the existing observations from the bore of interest and its surrounding bores is used to modify the estimated observation values. Estimates were only used if the location of the bore is critical to filling a gap in the data, and there was no other available data.*

Page 33

> *The period of 18/04/1993 to 29/9/1995 was chosen based on a number of factors: -*
>
> - *There was a fairly constant decline in the groundwater levels of most bores over this period*
> - *There was little to no recharge during this period*
> - *The dates are around the reading of meters*
> - *All relevant meters had been installed by April 1993*
>
> *As there was little to no recharge in the model domain during this period, recharge ceases to be an unknown in the model, and the aquifer material parameters (hydraulic conductivity and storativity) can be 'reliably' calibrated, as they are conceptually the only unknowns.*

Does "little or no recharge" mean no releases and no flow in the creeks? The fact that groundwater elevation declined does not necessarily mean no recharge in our opinion. Page 35 states:

> *Although the period of April 1993 to September 1995 was chosen for its lack of recharge, there was still recharge of quantifiable levels, and as such they need to be included in the model for completeness.*

The statements on Page 33 and 35 appear to be in conflict. We suggest that the best and most transparent way for modelling groundwater - surface water interaction is inside the model using the RIVER package. Importing time-series recharge values from outside the model without a proper discussion on how they were estimated is, in our opinion, not adequate for a model on which water allocation will be based.

Page 34

> *The initial conditions are the head values supplied to each active cell in the model domain at the start of the model run (i.e. time = 0). Ideally the initial conditions are sourced from the results of a 'steady state' model run representing the situation at the time chosen to start the transient model. A steady state model was constructed for this task, however it failed to converge with all the available solvers. This is likely to be because the aquifer was not in a steady state in April 1993, and that the little recharge that was taking place around this time was not enough to balance the groundwater extraction that was taking place.*
>
> *As there was no chance of obtaining these values via a steady state model, the starting head values for each cell were gained from the contouring of known waterlevel observations at the bores. Therefore the initial condition values were generated through contouring of bore waterlevels interpolated to the starting date of 18/04/1993 – leading to the results in Figure 11. The elevations shown in this figure are in metres of AHD.*

Page 35

> *Groundwater extraction values were available for the majority of the model area, and certainly the areas of main interest to allocation. The areas within the model, but outside the proclaimed area (Sandy Creek and down valley of Kentville Weir area) didn't have metered groundwater extraction available, so estimates of groundwater extraction were used.*
>
> *Groundwater use in Sandy creek was done on an area basis where a volume of 1.8 ML/ha was used and applied to cells within an area of cropping activity of the model. This area is shown in Figure 12 as green cells.*
>
> *An extraction volume for bores outside of the proclaimed area down valley of Kentville Weir were estimated by examination of other nearby bores and was carried out by SWP staff. These bores and estimates are presented in Appendix 1.*

Page 35

> *Although the period of April 1993 to September 1995 was chosen for its lack of recharge, there was still recharge of quantifiable levels, and as such they need to be included in the model for completeness. There was some flow in Laidley Creek during the period of interest, as well as some water stored in Glenore Grove Weir. Also within the model area there was stream recharge from the backing up of water from Brightview Weir. These recharge occurrences were entered into the model through the recharge package. In the recharge package, a depth of recharge is supplied for the relevant cells, which is converted to a volume of recharge using the cell's area. Cells that contain large enough sections of the creeks were defined as recharge cells. Recharge volume estimates have been gauged from observation of the losses experienced between points in the creeks. Total recharge volume to the aquifer in this model run is 2014.7ML, giving a yearly average of 823ML. The stress period break-up of this total is shown in Table 7.*
>
> *Recharge volume estimates have been gauged from observation of the losses experienced between points in the creeks. Total recharge volume to the aquifer in this model run is 2014.7ML, giving a yearly average of 823ML. The stress period break-up of this total is shown in Table 7.*
>
> *When these recharge volumes are compared to the groundwater extraction rates quoted in Table 6, recharge during the model run is only a mere 4.4% of the total groundwater extraction. From this it can be demonstrated how little recharge actually took place during the model run – even if the recharge values are out by 100%, there would still be very little recharge compared to the groundwater extraction.*

Considering the dominance of groundwater extraction on the groundwater balance, a similar discussion, on the uncertainty associated with groundwater extraction, should have been provided. This is because small uncertainties in groundwater extraction may cause large changes in the 'calibrated' model.

> *Recharge volume estimates have been gauged from observation of the losses experienced between points in the creeks.*

Considering the importance of surface-groundwater interaction, the methodology should have been described or a publication/report should have been referred to. How were the creek gauging data processed, how frequent were the measurements, did they cover the entire Stage 1?

> *In Stage 2 of the project the recharge zones are redefined through an exhaustive calibration process, thus the zones used for this calibration run are merely estimates, and the total volume entering the system is the important component. The recharge areas defined here are only relevant to Stage 1.*

We understand that Stage 1 refers conditions that were dryer than Stage 2. As such we expected to see the recharge zones identified in Stage 1 to "grow" for Stage 2 (i.e. keep the Stage 1 recharge zones and add to those). The Stage 2 recharge zones, based on Figures 13 and 18 of DNRM (2000), do not appear to include those from Stage 1.

Page 37

> *As mentioned in the conceptualisation this boundary condition was setup to replicate the water movement at the point where the alluvium continued on past the edge of the active model. Twenty-five cells are used in the modelling of this boundary and their locations can be seen in Figure 6.*

Fixed-head cells are the most restrictive of boundary conditions and should be used if no other boundary conditions work. This is because these cells take away/supply all the water from/into the model regardless whether the resultant fluxes are realistic or not. Are these fixed-head cells far away from recharge cells and extracting bores, in particular in the downstream end of the model? If not, the model construction locally may be incorrect. Fixed heads, as the name suggest, tie the groundwater head at both upstream and downstream ends and the model, in our opinion, and would be overly constrained in a long and narrow alluvium such as DNRM (2000). The model would interpolate between the upstream and downstream end with limited freedom to alter those locally due to local recharge/extraction.

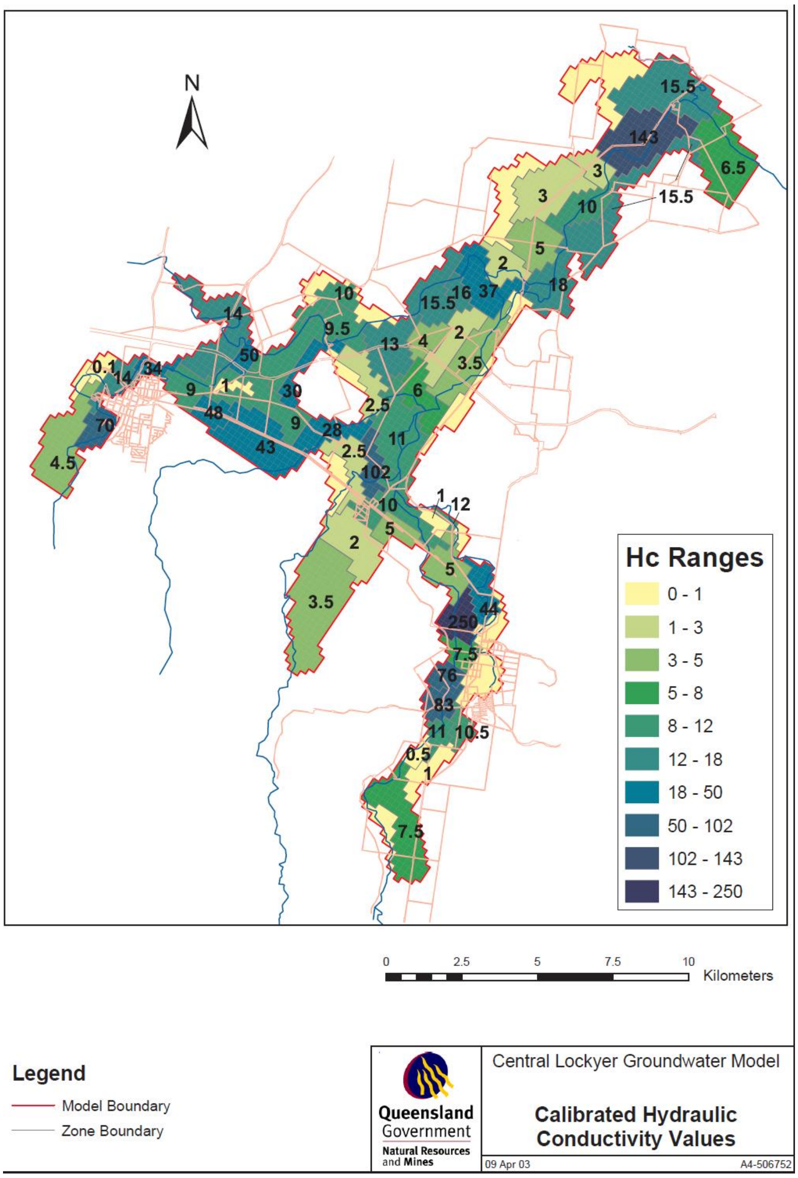
Page 39

The parameter zonation is extensive with 53 similar zones for conductivity and storage values. This is a high number of zones, however it is required due to the highly channelised and variable structure of the aquifer. Two things were considered during the zonation process:

- *Zonation should represent the hydrogeological variations of the aquifer being modelled.*
- *Each parameter should have an effect on at least 1 observation for calibration purposes.*

Fifty-three (53) zones are assigned for the 3214 active cells are, in our opinion, contrary to the well-developed modelling practise of working from simple toward complex. It also suggests that the big picture, model-wide calibration, will be lost through a set of tedious local calibrations. Such a model will undoubtedly calibrate, but would it be realistic?

Figure 15, reproduced below, indicates the existence of zones with straight, unnatural looking boundaries and some zones with huge contrast in adjoining hydraulic conductivity: 250 m/day vs 5 m/day or 7.5 m/day and 143 m/day vs 3 m/day. It is difficult to comprehend how such alluvial system developed and how these contrasts can be justified. In our view, the anomalously high values are the artefact of adopting a one-layer model and excluding the sandstones. The model probably initially dealt with these by very high heads and in subsequent error minimisation runs attempted to distribute the recharges locally. Because there was not enough transmissivity (product of hydraulic conductivity and thickness) in the one-layer alluvium, the thickness being limited the hydraulic conductivity had to be increased.



Page 41

> *The hydraulic conductivity values vary from 0.1 to 250 m/day, with only one (zone 9) of the 53 zones reaching the maximum value. The strata logs in this area show that the alluvial material is mostly made up of coarse gravel, and even some instances of boulders – hence high conductivity was expected in this area.*

From the descriptions provided and in the absence a pump test results in DNRM (2000), the maximum hydraulic conductivity (k) value of 250 m/day appears to be unrealistic and in our experience a k < 50 m/d would have been more appropriate.

> *It is also interesting to note that the hydraulic conductivity values from PEST seem to show some channelisation as well. Assessing all 3214 cells produces an average value of hydraulic conductivity for the model of 20.6 metres per day.*

PEST will work towards the minimisation of errors within the parameter bounds and it should have been explained that by varying the dominant aspect of the water budget (in Stage 1 extraction) another set of hydraulic parameters could have provided a similar calibration. It is important not to 'overdo' the error minimisation process and accept a larger error with realistic hydraulic parameters and lesser number of zones.

Page 42

> *Figure 17 (1-18) show the model and observed hydrographs from Stages 1 and 2 for the 103 observation bores.*
>
> *Stage 1 of the modelling process utilises 1536 observation points for the purposes of calibration.*

How do 103 bores result in 1536 observation points? Or is it the number of (time) observations? The resulting 1.05 m RMS error is low.

Page 43

> *Therefore it can be said that there is net loss from storage over the model domain of 43232 ML over the 2.45 years of the model run.*

We converted the quantities supplied to water heights by dividing the volumes with the total area of the active model cells:

- Average loss from storage:

  43232 10^3 m^3/(2.45 yrs x 3214 cells at 200 m x 200 m) = 0.137 m/yr

- Average Extraction

  45661 10^3 m^3/(2.45 yrs x 3214 cells at 200 m x 200 m) = 0.145 m/yr (1.45 ML/ha).

Extraction is almost entirely sourced from storage loss because the model had no choice other than source well extraction from storage dominantly. This is because in- and outfluxes were fixed heads and recharge was relatively small (Table 6, recharge during the model run is only 4.4% of the total groundwater extraction). And fixed head cells will always supply/take away the small flux required to balance the water budget.

Page 44

> *Examination of the variation away from the calculated phi of 1687, the sensitivity of each parameter can be gauged. The parameter values were increased and decreased by 20% and the phi value calculated and recorded.*

Noting the results of the water budget, of pivotal interest would have been the sensitivity of the model to extraction rates. Our view is that relatively small errors in extraction may have caused relatively large changes in the calibrated hydraulic conductivity.

Page 45

> *Completion of Stage 1 allowed for the commencement of Stage 2. Stage 1 involved the calibration of the aquifer parameters on the 'falling limb' of the bore hydrograph between April 1993 and September 1995. Stage 2 is a continuation (in time, from September 1995 to June 1997) of the Stage 1 model run.*
>
> *The main aim of Stage 2 was to define the sections of the creeks that receive recharge, and to determine possible maximums for these areas. This was achieved through calibration of recharge during the historical period immediately following the period used in Stage 1. During this time the aquifer parameters previously calibrated (Stage 1) where held constant, while values of recharge for the additional 7 stress periods were allowed to vary during a calibration.*
>
> *Stage 2 extends the existing Stage 1 model run by an additional 7 stress periods taking the total to 22 stress periods. … Again these periods were predominately defined from meter reading dates.*

Page 46

The majority of groundwater extraction for the model run has been sourced from the metering of irrigation bores. The first 15 stress periods of the model run are exactly the same as Stage 1. The additional 7 stress periods use estimates of usage for the key areas outside the proclaimed area boundary (Sandy Creek and Brightview Weir areas) - in a similar method to Stage 1. The values of usage for the additional 7 stress periods appear in Table 10. Again, a flat rate of 1.8 ML/ha was assumed for the Sandy Creek zone (see Figure 12) and extraction from the Brightview Weir area was estimated by nearby metered bore extractions.

Pages 47-48

The purpose of this calibration is to define the areas along the creek where recharge takes place, and then to calibrate volumes of recharge required to reproduce the aquifers response to the recharge event. This "two step" process is executed together due to the volumes for each zone needing to be assessed (calibrated) to determine the relevance of the zone (position and size).

Initially zones were set up along the entire length of the creek – where any cells containing any portion of any creek were used. This zonation was then subdivided based on initial thoughts of where recharge was and was not occurring. The model was then allowed to calibrate recharge values for the cells zoned for calibration.

After the calibration was complete, the recharge volumes were examined and decisions were made regarding whether the zone should be used, removed or modified. Strata information also played a key role in the assessment of the recharge zonation, some of which can be seen in the cross-section analysis (section 5.2.1.1).

One of the purposes of this calibration was to find the likely maximum recharge rates for each zone for further use in Stage 3 of the project. With this in mind there was little requirement for constraining of the recharge volumes being calibrated. Where a particular parameter did produce a very large recharge rate – it was investigated. The large rate was usually due to that particular parameter being insensitive. Parameter insensitivity refers to the condition where a parameter can be varied by a large amount with little or no change in the models response in comparison to the observed data. When this occurs in PEST, the software allows an insensitive parameter to vary greatly to seek out a point where it will become sensitive to the observed data. When parameters did become too high (above reality) and were obviously sensitive, they were constrained to a lower value – based on how they had varied on previous optimisations in the calibration process.

Recharge rates will depend on whether the recharge areas are assigned correctly or not. Surely data independent from the model (surface water budget, gauging data, surface water and groundwater elevations) could have also been used?

The final zonation of the recharge zones appears in Figure 18. Thirty-four individual zones were decided upon. These 34 zones could be further subdivided to increase the calibration "closeness of fit" - but this would also involve increasing the number of zones requiring extended calibration of recharge values for each stress period both in Stage2 and Stage 3. The final total of 34 zones was the balance point between the model's ability to replicate the overall recharge processes and the required effort to calibrate the recharge values for the zones.

It was pleasing to see that the calibrated recharge volumes during periods of releases from the dams only, were very similar to those volumes estimated by SWP staff using observed stream flow loss data and allowances for surface water use and evaporation.

Thoughts on where recharge was not occurring were replicated in the results from the calibration of recharge values, where recharge volumes became very small.

The resultant model appears to have 53 hydraulic and 34 recharge zones. Far too complex and would always calibrate locally in our opinion.

Page 50

The average error for the calibration is 0.87 m, which indicates a good fit.

The water budget for Stage 2 indicates vastly different results from Stage 1: wells extract 18185 ML (0.081 m/yr) while recharge from surface water 48984 ML (0.217 m/yr over the entire active model area). This is consistent with a major recharge event and the observation that groundwater use was less because of increased rainfall.

Overall, for both stages, the water budget indicates that 63789 ML extraction, sourced from 50999 ML recharge, 12145 ML storage and a small component through the fixed heads. Again, as for Stage 1, the model is setup on a way that the water budget gain/deficit will always be eliminated by the fixed heads.

Page 52

> *At the completion of Stages 1 and 2 aquifer parameters have been calibrated, recharge zones have been defined and the 1996 recharge event has been calibrated producing likely maximum recharge rates. The next stage is to generate a 10-year model run going back even further into history. The historical metered use has been estimated wherever meters were not available. Using the calibrated aquifer parameters the model run was extended back to July 1987 from April 1993.*
>
> *Utilising the maximum recharge rates and recharge zones defined in Stage 2, the values for recharge can be calibrated for these earlier stress periods.*
>
> *The model run involving all 3 stages forms a continuous 10-year period. This extended model run can be used to evaluate various management decisions relating to recharge (in the form of releases) and allocation (groundwater extraction).*

Page 53

> *The groundwater extraction for the additional Stage 3 requirements utilised, where available, metered groundwater extraction, extending back to around 1989 for some sections of the model area. The remaining groundwater extraction required estimation. State Water Project staff carried out the estimation of groundwater usage. Development of the area had not changed much in the 1987 to the mid 1990's, meaning that extrapolation of typical recorded usages back to the start of the model could be achieved with a level of assumed accuracy, factoring in allowances for climate.*

Page 55

> *Waterlevel observations have been taken at observation bores throughout the model domain. Unfortunately a few of the 103 bores used in the calibration were only drilled during the full model run time, and as such they do not have the required length of record for complete calibration. However these bores were added to the calibration because of the relevance of their locations to the calibration. Non-existent observations were estimated whenever required based on surrounding bore values.*

Pages 57-58

The average error, 0.9 m is good again.

The stage 3 water budget indicates recharge, 115874 ML (0.155 m/yr), balancing 92317 ML (0.124 m/yr) extraction and a storage increase of 25161 ML (0.034 m/yr) calculated for all active model cells.

Overall, for the entire 10 years of model, the water budget indicates recharge, 166872 ML (0.130 m/yr), balancing 157243 ML (0.122 m/yr) extraction and a storage increase of 11843 ML (0.009 m/yr) calculated for all active model cells. The water budget indicates that the most important and dominant factors are recharge (Stages 1 and 2) and groundwater extraction (all stages).

Page 59

Several scenarios were constructed:

- 9.1 Constant use, natural recharge (streams and weirs, use at all applicable model cells);
- 9.2 Constant recharge (unlimited volumes of water available in Bill Gunn Dam and Lake Clarendon for release when natural flows were not occurring) and constant use;
- 9.3 Optimum differential use (14 subareas) and actual (modelled total recharge) recharge; and
- 9.4 Optimum differential use (14 subareas) and actual (modelled total recharge) recharge and release from Lake Clarendon.

> *By knowing what water was released from the dams during which periods and by using available information on what part of the releases went where, model calibrated recharge was divided into natural and release sourced recharge components. Only 16 of the 34 recharge zones are affected by releases.*

It is unclear what is the definition for “natural”. For us, ‘natural’ suggest pre-lakes and pre-weir construction. The text above, however, suggests all recharges from surface water, including the weirs constructed for enhanced recharge. Those weirs could hardly be called natural?

Page 61

> *It can be concluded that allocating groundwater evenly across the area would require allocation levels of less than 2ML per hectare to be sustainable under natural recharge conditions.*
>
> *It is important to note that the historical metered / estimated water use was an average of some 15,700 Megalitres per year and at 2 ML/ha the average use over the same ten year period was 13160 ML/yr.*

Pages 62-64

> *Following on from the natural recharge only scenario, the model was run for the same extraction scenarios with modifications made to the recharge occurring. The modifications involve assuming that there were unlimited volumes of water available from Bill Gunn and Lake Clarendon dams for release.*
>
> *For each recharge zone affected by releases, a recharge rate that is assumed to have occurred during releases was determined using previously calibrated data. This data is shown in Appendix 10. The original recharge file, containing the recharge data that the model had determined to occur in the 10-year period, was then used as a basis for these new scenarios. In any stress period where recharge in the original file for a particular recharge zone was less than that of the calculated release recharge rate, for that same zone, the file figure was amended upwards to equal the release recharge figure.*
>
> *Even with continuous recharge an extraction rate of 2ML/ha from the aquifer could not be sustained in the long term.*
>
> *The further obvious point is that the recharge conditions used in this group of scenarios were unrealistically high. The actual conditions that will exist with both dams supplying water intermittently will provide significantly less recharge.*
>
> *In short, if groundwater is allocated equally across the proclaimed area, then the allocation rate will need to be less than 2 ML/ha.*
>
> *A comparison of the results of the 2 ML/ha natural recharge run against the 2 ML/ha continuous recharge demonstrates that most areas improve significantly with the continuous recharge from the dams.*
>
> *The run which used 1ML/ha water use in the Crowley Vale area and 2.5 ML/ha elsewhere would support the conclusion that allowing different levels of use in different areas would allow greater use of the resource overall whilst still maintaining viable groundwater levels in the poor recharge areas.*
>
> *It should also be noted that under these continuous recharge conditions the ideal spread of use would also see a reduction in use below 2.5 ML/ha in the areas south of the college and just north of Forest Hill. Also it is likely that use could be increased adjacent the good recharge areas on Lockyer and Laidley Creeks.*

Page 64

In work carried out on the natural recharge scenarios (see section 9.1) and the constant recharge scenarios (see section 9.2) it was identified that a system that allowed different levels of use in different areas may allow a more efficient overall use of the resource.

It was then decided to split the area into 14 sub areas – see Figure 36 for the zone distribution. The principal behind this zoning was to group cells together with similar access to recharge areas. Firstly the 103 water level calibration bores were examined and a 'target' water level in each bore was determined which would be desirable as the average water level for the model period. Generally this involved selecting the water level in July of 1990 and the water level at January 1994 for each bore and calculate the average of these two figures as the target water level.

The reasoning for these dates being that July 1990 saw groundwater levels in many of the areas peak and water levels in January 1994 were at a low to moderate level but not yet at the all time lows they would reach over the following 18 months. The intention was to use PEST to calibrate constant extraction rates for the model run in each zone. This would result in achieving the best fit possible to the requested water levels in each of the 103 calibration bores.

Pages 64-65

As a refinement of the work carried out in 9.3, a scenario was set up to calibrate optimum water use from 1987 to 1997 but on this occasion simulating the additional recharge that would have been available had Lake Clarendon been constructed in 1987.

Water balances have been carried out on Bill Gunn Dam and Lake Clarendon for the ten-year period 1987 – 1997. A relationship between the harvesting potential to Bill Gunn dam (constructed 1987) and Lake Clarendon (1992) was established by looking at four significant harvesting events between 1995 and 1999.

This relationship was used to estimate water that would have been harvested to Lake Clarendon from 1987 – 1992 had Lake Clarendon been constructed. Releases were scheduled from both dams in unison according to current release rules.

It was assumed that 30% of all water released to Lockyer and Laidley creeks from the dams was used by surface water creek pump users. It was also assumed that the water used by the Morton Vale pipeline was 267 ML per month or 3200 ML/yr.

The groundwater model was used to determine release rates from the dams. The maximum recharge rate in each recharge zone was known and it is also known that at other times when groundwater levels are higher, that recharge rates drop.

Proposed recharge rates were placed in the recharge file and if projected water levels in the calibration bore were too high the recharge rates were adjusted until realistic peak water levels were not exceeded.

Once the recharge rate was known in each recharge zone for a stress period, then the correct release rate could be determined.

All this work was carried out initially using historical use and then extraction was allowed to calibrate to achieve target water levels.

The text above appears poorly written and incomprehensible.

Page 69

By using the calibrated extraction figures supplied in Table 21 and the area of cells within each sub area where that water has been extracted from, yield figures for the ten-year period can be determined. These are detailed below in Table 22.

Figure 39 demonstrates water levels at July 1997 as a result of simulated release conditions assisting natural recharge and water extraction as calibrated above.

These yield figures now provide the basis for setting allocations. In some areas there will need be further analysis of the performance of the water levels in the calibration bores, and how they compare to the targets. However, overall the information above provides a very sound basis for setting sustainable allocation levels in the Central Lockyer area.

It is not clear why the yield figures serve as a basis for future allocations.

3. Review of DNRM (2018)

3.1. Summary

DNRM (2018) completed this report to demonstrate the recharge processes within the existing benefitted groundwater area of the Central Lockyer Valley water supply scheme and how those processes are linked to releases from the scheme dams.

The report also examines parcels of land where the underlying aquifer is considered to be deriving significant benefit from the scheme, but the parcels are not currently included in the benefitted area. DNRM (2018) recommends incorporating the three areas to the existing benefitted groundwater area.

3.2. Important issues identified by the review

There are two major issues identified through this review of DNRM (2000):

- reliance on the DNRM (2000) model and the use circular logic; and
- incomplete and undocumented conceptualisation of surface water recharge to groundwater.

3.2.1. Reliance on the DNRM (2000) model and the use circular logic

In places (for example pages 6 and 65-70), DNRM (2018) appears to claim that the similarity of the results between DNRM (2000 and 2018) provides increased confidence in the results. We disagree and suggest that the similarity is due using the same, or similar assumptions.

On page 65-70, the volumes of groundwater recharge from releases are described:

"Additionally, it is noted in the Central Lockyer Groundwater Model report, Appendix 9, that when carrying out water balances on release periods evapotranspiration is estimated at 20% of release volume. It is also known that the peak surface water use was recorded in the 1996/97 water year. In this year metered surface water use was 25% of total releases from Lake Dyer and Lake Clarendon. If an evapotranspiration figure of 20% and a surface water use figure of 25% is applied to the release figures documented in Table 2, an approximation of annual volumes of release water available for groundwater recharge can be made."

We checked Appendix 9 of DNRM (2000), it uses the word "*allow*" which to us indicates that an assumption/allowance was made. To us, that is different from the word "*estimated*".

The text on page 70 refers to "*observed*" recharge rates. These, in our opinion, are not "*observed*" in the meaning that they are not measured/monitored, but using the various words of DNRM (2018) are "*estimated*" (Table 3), "*likely*" (page 66) or "*approximate*" (Table 5). Our interpretation is that DNRM (2018) uses the same assumption as DNRM (2000) did:

"The figures demonstrate that the model is simulating similar recharge rates to those observed, thus providing confidence not only in the model but also in the water balance methods used to observe recharge rates."

Using the same assumptions as in the DNRM (2000) model and arriving to the same conclusion and claiming this as providing high confidence in the result is circular logic and should not be taken as a proof of high confidence in the results.

3.2.2. Incomplete and undocumented conceptualisation of surface water recharge to groundwater

DNRM (2018) refers to the conceptualisation of DNRM (2000) and on page 5 states that:

"It is only where the creek incises this clay layer that recharge can occur from the creek to the aquifer".

The statement above is incorrect. Recharge from a surface watercourse to groundwater will depend on the relationship between the heads in the surface water and groundwater and the hydraulic conductivity and geometry of the intervening river bed materials. A creek does not necessarily have to incise the clay layer. Maximum recharge occurs when the groundwater head is below the bottom of the riverbed and the riverbed material is conductive.

The section on pages 65-70 is entitled "*Volumes of Groundwater Recharge from Releases*". The title of this section suggested to us a quantitative assessment of recharges. Instead, estimated snapshot recharges in time are tabulated.

In our opinion, a description of surface water – groundwater interaction is missing from this section of DNRM (2018). Using snapshots in time to estimate recharge is fine, but the following aspects of surface water – groundwater interaction should have also been described:

- groundwater –surface water interaction is dynamic and may vary with time and space;
- recharge is time-dependent;
- recharge depends on surface water and groundwater heads;
- recharge depends on surface water head above river bed if groundwater head is below the river bed bottom; and
- recharge depends on groundwater head if that is above the river bed.

3.2.3. Detailed extracts and comments

Extracts are indented and in *italics* and within a text box, our comments (where applicable) are in non-italics and outside of the text box. All are referenced to page numbers in DNRM (2018).

Page 1

This report demonstrates the recharge processes within the existing benefited groundwater area of the Central Lockyer Valley water supply scheme and how those processes are linked to releases from the scheme dams.

Within each Management area of the scheme:

- *Primary recharge zones are identified*
- *Groundwater gradients (direction of groundwater flow) away from these recharge zones are defined*
- *The relationship between releases from the dams and groundwater levels are demonstrated.*

The report also examines and makes recommendations on those parcels of land where the underlying aquifer is considered to be deriving significant benefit from the scheme but the parcels are not currently included in the benefited area.

Page 2

Information obtained since the initial setting of the benefitted area indicates that there are some parcels of land currently outside the mapped benefitted area which are receiving significant benefit and so should now be included.

The "information" is not described or referenced, this is considered to be as an important aspect of the report which is unavailable.

Page 5

DNRM (2018) refers to the conceptualisation of DNRM (2000).

> *Therefore a recharge source exists in the creek where there is a connection between the water in the creek and the aquifer. Permeable material (e.g. sand, gravel, loam, sandy or silty clay) in the base of the creek extending down to the top of the aquifer provides this connection. Heavy clays impede the movement of water and are the primary reason why there is little direct recharge through the soil profile in the Central Lockyer as these clays generally exist immediately below the soil over most of the area.* ***It is only where the creek incises this clay layer that recharge can occur from the creek to the aquifer.*** *Information obtained since the initial setting of the benefitted area indicates that there are some parcels of land currently outside the mapped benefitted area which are receiving significant benefit and so should now be included.*

The above text in italics and bold is incorrect. Recharge from a surface watercourse to groundwater will depend on the relationship between the heads in the surface water and groundwater and the hydraulic conductivity and geometry of the intervening river bed materials.

A creek does not necessarily have to incise the clay layer. Maximum recharge occurs when the groundwater head is below the bottom of the riverbed and the riverbed material is conductive.

Also refer to our comments about the clays (on page 10 of this report, referring Page of DNRM, 2000 comments).

Page 6

> *The Central Lockyer groundwater model was developed in the late 1990's and finalised in 2000. In the model, recharge zones were identified at various model cells within the model area. The cells represented those areas where recharge was occurring or potentially may be occurring, and together these cells form recharge zones within the model. Recharge rates are allowed to vary in the model from one zone to another. Initially, the locations of the zones were identified utilising the local knowledge of department staff, based on examination of bore water level responses to recharge events over many years in combination with knowledge of the local hydrogeology. The zones were then altered in a process to more accurately match model predicted water level behaviour with that historically observed.*

Similar to DNRM (2000), the text does not explain or reference how the recharge rates were estimated. The only reference is to local knowledge of department staff, which is somewhat vague for a water allocation plan.

> *Note that the majority of the recharge zones adopted in the model are located on water courses, which is in line with the conceptualisation of where most recharge in the area occurs.*

This statement should not be taken as a confirmation of the model; rather that an assumption in conceptual hydrogeology that was transferred to the numerical model.

Pages 10-65

These sections of DNRM (2018) examine the relationship between the CLVWSS and bore hydrographs by management areas. In general, these sections consist of several figures and accompanying text. Most of the figures are not comprehensive, i.e. show only certain aspects of hydrology or hydrogeology. The management area maps at the beginning of each section could have been improved by plotting monitoring bores and stream gauging stations; bore hydrographs could have been overlayed with stream heights and/or rainfall. In addition, the groundwater elevation contour maps could have displayed surface water heads for the corresponding times to illustrate the surface water groundwater relationships.

These sections provide a qualitative reasoning for how groundwater elevations in the alluvium benefitted from the CLVWSS. In general, the explanations are based on well-established observations in hydrology, i.e. bores adjacent to a creek react to floods/releases in the creek faster and to larger extent than those further away.

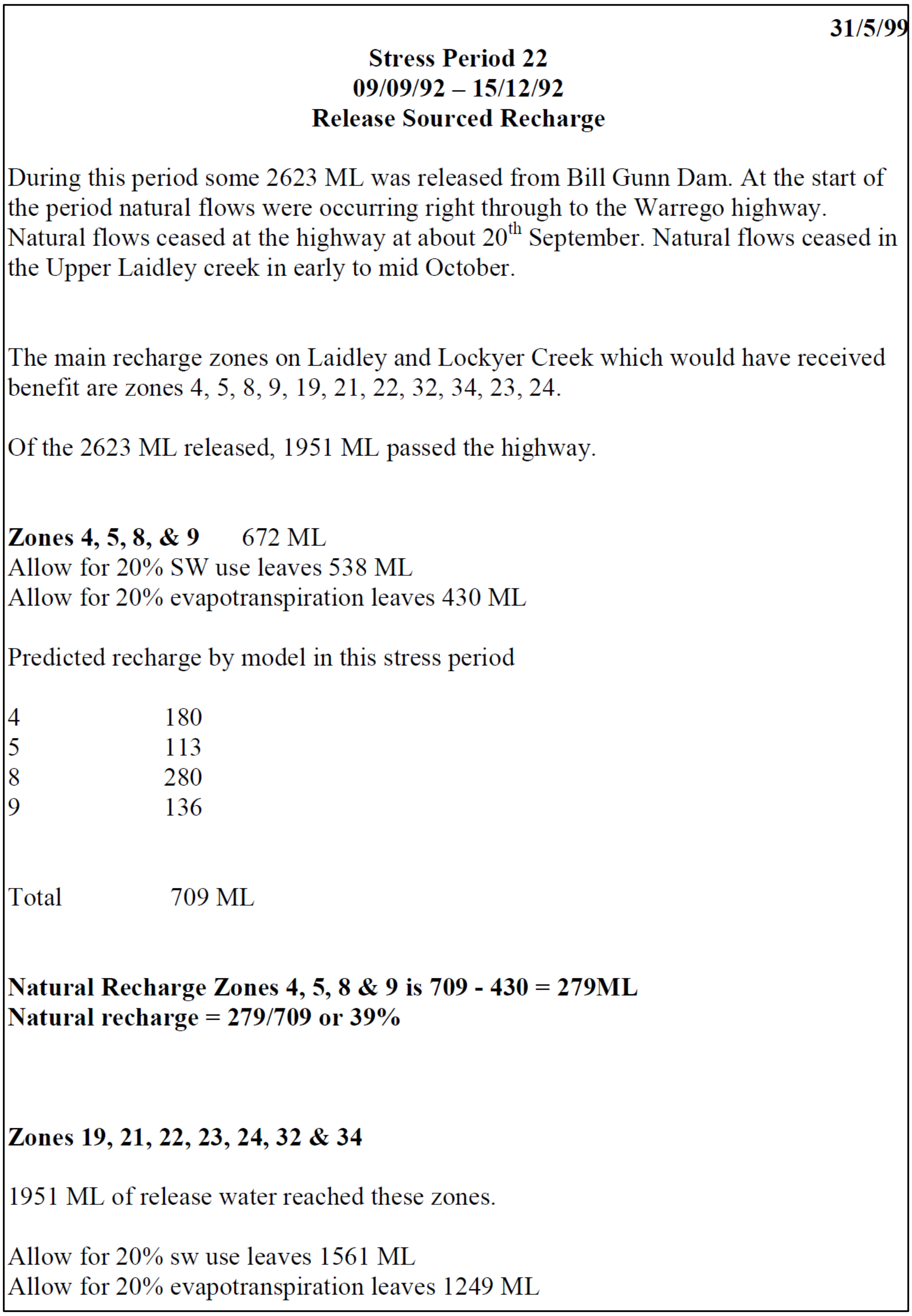
It is unclear why the model, if it was considered fit for purpose by DNRM, was not used to separate natural and 'benefitted' processes? After all, the benefits should be measured quantitatively and the DNRM (2000) model is the only tool available for the Central Lockyer Valley.

Page 65-70, Volumes of Groundwater Recharge from Releases

The title of this section suggested to us a quantitative assessment of recharges. Instead, estimated snapshot recharges in time are tabulated.

> *Additionally, it is noted in the Central Lockyer Groundwater Model report, Appendix 9, that when carrying out water balances on release periods evapotranspiration is estimated at 20% of release volume. It is also known that the peak surface water use was recorded in the 1996/97 water year. In this year metered surface water use was 25% of total releases from Lake Dyer and Lake Clarendon. If an evapotranspiration figure of 20% and a surface water use figure of 25% is applied to the release figures documented in Table 2, an approximation of annual volumes of release water available for groundwater recharge can be made.*

We checked Appendix 9 of DNRM (2000) and reproduced the entire page below (Figure 3.1). DNRM (2000) uses the word “allow” which to us indicates that an assumption/allowance was made. To us, that is different from the word “estimated”. Our interpretation is that DNRM (2018) uses the same assumption as DNRM (2000) did.



31/5/99

Stress Period 22
09/09/92 – 15/12/92
Release Sourced Recharge

During this period some 2623 ML was released from Bill Gunn Dam. At the start of the period natural flows were occurring right through to the Warrego highway. Natural flows ceased at the highway at about 20th September. Natural flows ceased in the Upper Laidley creek in early to mid October.

The main recharge zones on Laidley and Lockyer Creek which would have received benefit are zones 4, 5, 8, 9, 19, 21, 22, 32, 34, 23, 24.

Of the 2623 ML released, 1951 ML passed the highway.

Zones 4, 5, 8, & 9 672 ML
Allow for 20% SW use leaves 538 ML
Allow for 20% evapotranspiration leaves 430 ML

Predicted recharge by model in this stress period

4	180
5	113
8	280
9	136
Total	709 ML

Natural Recharge Zones 4, 5, 8 & 9 is 709 - 430 = 279ML
Natural recharge = 279/709 or 39%

Zones 19, 21, 22, 23, 24, 32 & 34

1951 ML of release water reached these zones.

Allow for 20% sw use leaves 1561 ML
Allow for 20% evapotranspiration leaves 1249 ML

Figure 3.1 Appendix 9 recharge calculations from DNRM (2018)

The figures demonstrate that the model is simulating similar recharge rates to those observed, thus providing confidence not only in the model but also in the water balance methods used to observe recharge rates.

Using the same assumptions as in the DNRM (2000) model and arriving to the same conclusion and claiming this as providing high confidence in the result is circular logic and should not be taken as a proof of high confidence in the results. We also note, with concern that the text above (on page 70) refers to "observed" recharge rates. These are not "observed" in the meaning that they are not measured/monitored but using the various words of DNRM (2018) are "estimated" (Table 3), "likely" (page 66) or "approximate" (Table 5). To us "estimated" is the most appropriate term and that should have been used consistently throughout pages 65-70.

In our opinion, a description of surface water – groundwater interaction is missing from this section of DNRM (2018). Using snapshots in time to estimate recharge is fine, but the following aspects of surface water – groundwater interaction should have been described:

- recharge is time-dependent;
- dependency on surface water- and groundwater head;
- dependency on surface water head above river bed if groundwater head is below the river bed bottom; and
- dependency on groundwater head if that is above the river bed.

Further explanation of how best to model to surface water – groundwater interaction is already provided on Page 13 (referring to the review of Page of DNRM, 2000).

4. Review of DES (2018)

4.1. Summary

The Department of Environment and Science (DES, 2018) completed a draft report to document the technical aspects of modelling two scenarios using the DNRM (2000) model with a time period extended to 2014. It is important to note that the DNRM (2000) model internal structure was not altered, the time extension refers to extending the period of inputs to the model.

Two scenarios were created. For Scenario One, the extractions in the Central Lockyer Groundwater Benefitted Area (CLGBA) are moderated by trigger levels in specific departmental trigger bores. Scenario Two assumes a fixed annual extraction of 13,671 ML from the benefitted zone.

Results indicate that when groundwater levels are relatively high, there is little difference between the simulated groundwater heads for the two scenarios. During extended dry periods the simulated groundwater head for Scenario Two is below that of Scenario One – a hardly surprising result considering the trigger levels would cut-in during prolonged dry periods.

4.2. Important issues identified by the review

There are two major issues identified through this review of DES (2018):

- although the time period of the model extended, DES (2018) still relies on the DNRM (2000) model; and
- simplistic assessment of irrigation needs.

4.2.1. Reliance on the DNRM (2000) model

It appears that period has been extended but the model structure and recharge/discharge remain unchanged from those of DNRM (2000). Therefore, the limitations of DNRM (2000), identified in Section 2.2, the lack of transparency in model documentation and in model building, the incomplete conceptual hydrogeology and the simplistic representation of surface water – groundwater interaction apply.

4.2.2. Simplistic assessment of irrigation needs

DES (2018) considers the 90th percentile of metered annual water use data over a 27-year period from July 1992 to June 2017 as a suitable basis for assessing the aspirational volume.

The 90th percentile, for 27 years, in practise means the third or fourth largest annual volume and it would favour higher historical rates or users who can claim smaller irrigation areas. In our experience, there are more robust methods for assessing irrigation needs.

It is also understood that a significant number of flowmeters applied to the irrigation bores within the scheme area are either not working or are providing erroneous readings. Where this is understood to be the case, estimates of pumping have been used within the model. Such reliance upon observed metered data and estimated input for model predictions brings into question the validity of the approach and the uncertainty of these data.

4.2.1. Detailed extracts and comments

Extracts are indented and in *italics* and within a text box, our comments (where applicable) are in non-italics and outside of the text box. All are referenced to page numbers in DES (2018).

Page 3

> *All water entitlements in the Central Lockyer Groundwater Benefited Area (CLGBA) will be subject to 'announced allocation' (AA) which will limit the aspirational volume that can be pumped each water year. The AA rule is based on measured groundwater levels.*

Page 5

> *This model has been extended for the period from 1 July 1987 to 30 June 2014 using MODFLOW 2000 and the same fix. This is referred to as the model for this assessment.*
>
> *The single layer model has 3214 active cells covering an area of about 13,000 ha (Figure 2). The model runs on a daily time step from 1 July 1987 to 30 June 2014. Water enters the model domain through recharge and from time-variant specified head boundaries in the upper reaches. Most recharge to the aquifer is received through creeks.*
>
> *Water is lost from the model predominantly through pumping which is used mainly for irrigation purposes. Water also leaves the model in lower reaches through time-variant specified head boundaries.*
>
> *The model simulates groundwater levels using extractions and recharge as the major inputs.*

It appears that period has been extended but the model structure and recharge/discharge remain unchanged.

> *The recharge sequence was obtained from the model using metered as well as estimated use and by adjusting recharge until the difference between the simulated groundwater levels and observed groundwater levels was minimised. For the purpose of this assessment it is assumed that Lake Clarendon has existed since 1987.*

Lake Clarendon was constructed in 1992.

> *Within the model domain there are three principal groundwater extraction zones. They are:*
>
> - *Benefited zone*
> - *Unbenefited zone*
> - *Sandy Creek zone.*
>
> *Central Lockyer Groundwater Benefited Area (CLGBA) is divided into six management zones (see Figure 2). There are 334 production bores in the CLGBA and the location of these bores are shown on Figure 2. Each bore has been assigned a proposed aspirational volume, which is a share of the proposed nominal volume across all the active bores for a draft water allocation (see Appendix B). The approach adopted by DNRME in determining aspirational volume for groundwater users in the Benefited zone is included in Appendix A.*
>
> *For the Unbenefited zone there are 299 production bores (see Figure 2). For this assessment the volume pumped from each bore is the historical metered use. The average annual pumping from these bores is 4,159 ML/a.*
>
> *In the Sandy Creek zone there are 110 model cells and each cell is deemed an extraction cell. For the period 1 July 1987 to 31 December 1999 the pump rate for each cell was 7.28 ML/a. From 1 January 2000, in accordance with lesser use estimate determined by DNRME, for the 84 cells upstream of bores 14320313A and 14320660A, the pump rate is 1.82 ML/a, while an extraction rate of zero is adopted for the remaining 26 cells. The average annual pumping from this zone is 453 ML/a.*

Page 6

> *The approach adopted by DNRME in determining aspirational volume for groundwater users in the Benefited zone is included in Appendix A*

Appendix A

We suspect the aspirational volume on page 6 is the same as nominal volume in Appendix A.

> *Nominal volumes for water allocation to take supplemented groundwater were derived using the following methodology:*
>
> *Step 1- Determine the 90th percentile value of metered water use data over a 27 year period from July 1992 to June 2017 for a property.*
>
> *Step 2- Determine the hectares of irrigable area utilising geology mapping and imagery data for parcels specified on the licence/s for the property.*
>
> *Step 3- Divide the 90th percentile value in Step 1 by the irrigable area obtained in Step 2.*
>
> *Step 4- Assign the calculated value from Step 3 to one of the following categories:*
>
> - *If the value is equal to 2 megalitres (ML) per hectare, then the volumetric conversion rate will be 2ML per hectare. The resulting allocation volume will be 2 ML multiplied by the irrigable area.*
> - *If the value is greater than 2ML but equal to or less than 3ML per hectare, then the volumetric conversion rate will be 3 ML per hectare. The resulting allocation volume will be 3 ML multiplied by the irrigable area.*
> - *If the value is greater than 3 ML per hectare, then the 90th percentile of historic metered water use for the property will be the allocation volume.*
>
> *Due to the variability in metered use data over the 27 year period, the 90th percentile is considered to be a suitable basis for the conversion methodology. This value will reflect use from dry periods through to wet years, but it does not take into account the highest record of take. The data that falls between the 90th to 100th percentiles may contain potential outliers or years of unusually high use. Assigning allocations considering these outliers for all underground water entitlements would be unsustainable when totalled together.*

The 90th percentile, for 27 years, in practise means the third or fourth largest annual volume and, in our opinion, would reflect wet years rather wet and dry years. We understand why the aspirational volume is set to higher than median, but do not follow why the process is designed so that it would favour higher historical rates or users who can claim smaller irrigation areas. There are more robust methods for assessing irrigation needs.

Cumulative frequency distribution curves for users would have been helpful in Appendix A.

Pages 8-10, Scenario One

For the bores in the CLGBA, it is proposed that a system of announced allocations (AA) be introduced based on groundwater levels (trigger levels) in specific departmental monitoring bores (trigger bores) selected to be representative of each management zone.

Ordinarily, the amount of groundwater take in a groundwater model is fixed for the duration of the model simulation period and is determined externally from the model.

In order to simulate announced allocations, the pumping from each bore needs to be internally adjusted during model simulations based on:

- *the simulated groundwater level at specified times and locations*
- *predetermined trigger levels at specified locations.*

The Groundwater Operational Management Package (GWOMP) developed by DERM in 2011, is used to simulate the effect of the proposed AA rules for the bores in the CLGBA.

Table 2 shows trigger bores within each management zone, trigger levels and corresponding AA level for that bore. There are in total 21 trigger bores used for AA calculations in this model. The locations of the trigger bores are shown in Figure 3 along with the management zones. (see Figure 4.1).

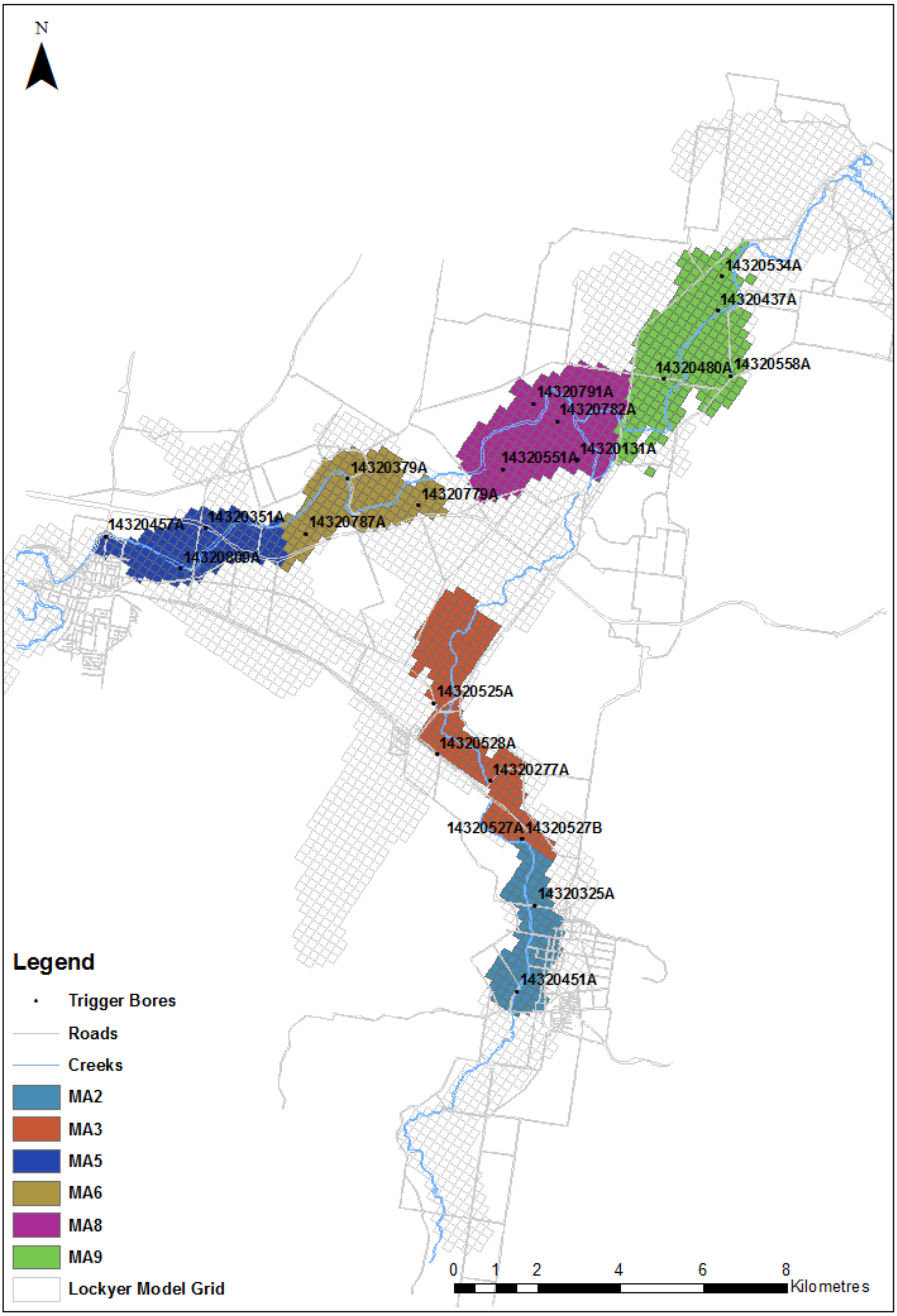


Figure 4.1 Trigger bores and management zones (after DES, 2018)

The proposed announced allocation level for each management zone is calculated by averaging the AA levels for trigger bores in that management zone. The AA is implemented at the beginning of the water year on 1 July and is fixed for the remainder of the water year. Owing to the minimum announced allocation level of 40% (i.e. a minimum pump rate of 40% aspirational volume), there may be times when the simulated groundwater level approaches the base of the model due to the fixed minimum announced pump rate. This is further discussed in Section 5.

Multi-node well package (Halford and Hanson, 2002) is used to model the pumping from the Unbenefited zone and Sandy Creek zone.

In this package, when the simulated water level in a pumping cell approaches the base of the aquifer the pump rate is reduced. This prevents the groundwater level in the model to drop below base of the model.

We assumed, on the basis of Page 6, that for the unbenefited zone the average annual extraction of 4,159 ML was used. In the Sandy Creek zone prior to 31 December 1999 the pump rate for each cell was set to 7.28 ML/year. From 1 January 2000, in accordance with lesser use estimate determined by DNRME, for the 84 cells upstream of bores 14320313A and 14320660A, the pump rate is 1.82 ML/year, while an extraction rate of zero is adopted for the remaining 26 cells. The average annual pumping from this zone is 453 ML/year.

Page 11, Scenario Two

The second scenario assumes a fixed annual take of 13,671 ML from the Benefited zone. No AA rules were imposed. The purpose of this scenario was to provide comparison with scenario one.

Since there is no adjustment to the pump rate during the simulation, it is more likely for groundwater levels to go below the base of the model.

For the Unbenefited zone and Sandy Creek zone the pump rate is modelled as outlined in scenario one.

Pages 12-18 results for Scenario 1

AA levels determined on the 1 July for each management zone for the period of simulation are presented in Table 3 and average between 61 and 76%.

The modelling results reveal there are 67 production cells (91 production bores) in CLGBA where the simulated groundwater level occasionally goes below the base of the model. These cells are defined as dry cells. As outlined in Section 3.1, when this occurs the model assumes one metre thick saturated layer to maintain announced pumping rate. These dry cells are identified in Figure 4. The average volume of the groundwater pumped from the 67 production cells, when the simulated groundwater level falls below the base of the model, is equivalent to 690 ML/a, compared to the average announced pumping rates of 9,370 ML/a. Accordingly, the reported announced pumping rates in Table 4 incorporate this additional groundwater which is not available.

Why not switch off the bores in dry cells? In our view, these cells going dry are the artefact of adopting a one-layer model and excluding the underlying sandstones. The sandstones may yield less groundwater, but their thickness would have easily provided ‘wet’ cells.

Page 18 results for Scenario 2

Since no AA rule was applied for CLGBA, the simulated pump rate volume is 13,671 ML/a.

Simulated groundwater levels for this scenario (red line) are also shown in Appendix C. For reference the observed groundwater levels at the observation bores are also presented.

It is seen from Appendix C that when groundwater levels are relatively high, there is little difference between the simulated groundwater level for scenario one and two. However, during extended periods of low recharge, simulated groundwater levels diverge.

This is hardly surprising result considering the trigger levels would cut-in during prolonged dry periods.

5. Conclusions

Barnett *et al.* (2012) provides the basic framework for numerical groundwater modelling in Australia. Although the DNRM (2000) model pre-dates Barnett *et al.* (2012), for the reasons we provided in Section 1.3 of this report (we understand that the proposed water allocation in the Central Lockyer Valley is based on DNRM, 2000) we completed Table 5.1 and Table 5.2, consistent with the recommendations of Barnett *et al.* (2012).

Barnett *et al.* (2012), the Australian Groundwater Modelling Guidelines issued by the National Water Commission (NWC), is widely used in Australia by both modellers and reviewers to assess if a model is fit for purpose, particularly for regulatory approval purposes. It was, for example, used in the Carmichael Coal Project Groundwater Flow Model Independent Review[1]: Barnett *et al.,* (2012) was also used in the land court of Queensland between the New Acland Coal Pty Ltd and objectors[2].

Table 2-1 of Barnett *et al.* (2012) provides the model confidence level classifications (characteristics and indicators) for three levels (Class 1 being the simplest and Class 3 being the most complex). Class 1 is for basic problems and models; whereas impact assessment models are generally considered Class 2 models. We associate an "aquifer simulator" model, required in our opinion for water allocation purposes for the Central Lockyer Valley, with a Class 3 classification. We came to this conclusion because of the following specific uses, relevant to the Central Lockyer Valley, that Barnett *et al.* (2012) considered appropriate for Class 3 models:

- provide information for sustainable yield assessments for high- value regional aquifer systems; and
- simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models.

The guidelines (Barnett et al., 2012) recommend the adoption of the following confidence level classification terminology, "*The degree of confidence with which a model's predictions can be used is a critical consideration in the development of any groundwater model*."

Factors that should be considered in establishing the model confidence-level classification (Class 1, Class 2 or Class 3 in order of increasing confidence) are presented in Table 2-1 of Barnett *et al.* (2012). That is *"A Class 1 model, for example, has relatively low confidence associated with any predictions and is therefore best suited for managing low- value resources (i.e. few groundwater users with few or low-value groundwater dependent ecosystems) for assessing impacts of low-risk developments or when the modelling objectives are relatively modest. The Class 1 model may also be appropriate for providing insight into processes of importance in particular settings and conditions. Class 2 and 3 models are suitable for assessing higher risk developments in higher-value aquifers."*

Based on our assessment of yes/no answers in Table 5.1 and Table 5.2, DNRM (2000) does not comply with the guideline requirements.

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[1] http://s3-ap-southeast-2.amazonaws.com/adani/pdf/Carmichael_Groundwater_Model_Review_HGL%2B(3).pdf

[2] http://envlaw.com.au/wp-content/uploads/acland100.pdf

Table 5.1 Compliance checklist from Barnett *et al*. (2012)

Question	Yes/No
1. Are the model objectives and model confidence level classification clearly stated?	No
2. Are the objectives satisfied?	No
3. Is the conceptual model consistent with objectives and confidence level classification?	No
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	No
5. Does the model design conform to best practice?	No
6. Is the model calibration satisfactory?	Yes
7. Are the calibrated parameter values and estimated fluxes plausible?	No
8. Do the model predictions conform to best practice?	No
9. Is the uncertainty associated with the predictions reported?	No
10. Is the model fit for purpose?	**No**

Table 5.2 Review checklist from Barnett *et al*. (2012)

Review Questions	Yes/ No	Comment
1. Planning		
1.1. Are the project objectives stated?	Yes	
1.2. Are the model objectives stated?	Yes	
1.3. Is it clear how the model will contribute to meeting the project objectives?	Yes	
1.4. Is a groundwater model the best option to address the project and model objectives?	Yes	
1.5. Is the target model confidence-level classification stated and justified?	No	
1.6. Are the planned limitations and exclusions of the model stated?	No	
2. Conceptualisation		
2.1. Has a literature review been completed, including examination of prior investigations?	No	Not documented in DNRM (2000)
2.2. Is the aquifer system adequately described?	No	
2.2.1. Hydrostratigraphy including aquifer type (porous, fractured rock …)	Yes	
2.2.2. Lateral extent, boundaries and significant internal features such as faults and regional folds	Yes	
2.2.3. Aquifer geometry including layer elevations and thicknesses	No	
2.2.4. Confined or unconfined flow and the variation of these conditions in space and time?	Yes	
2.3. Have data on groundwater stresses been collected and analysed?	Yes	
2.3.1. Recharge from rainfall, irrigation, floods, lakes	No	Rainfall recharge is missing
2.3.2. River or lake stage heights	No	But provided as externally calculated quantities
2.3.3. Groundwater usage (pumping, returns etc)	Yes	

Review Questions	Yes/ No	Comment
2.3.4. Evapotranspiration	No	
2.3.5. Other?	No	Interaction between hydrostratigraphic units is missing
2.4. Have groundwater level observations been collected and analysed?	Yes	But not published
2.4.1. Selection of representative bore hydrographs	Yes	But not published
2.4.2. Comparison of hydrographs	No	
2.4.3. Effect of stresses on hydrographs	No	
2.4.4. Watertable maps/piezometric surfaces?	No	
2.4.5. If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A	
2.5. Have flow observations been collected and analysed?	No	But provided as externally calculated quantities
2.5.1. Baseflow in rivers	No	
2.5.2. Discharge in springs	N/A	
2.5.3. Location of diffuse discharge areas?	No	
2.6. Is the measurement error or data uncertainty reported?	No	
2.6.1. Measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	No	
2.6.2. Spatial variability/heterogeneity of parameters	No	
2.6.3. Interpolation algorithm(s) and uncertainty of gridded data?	No	
2.7. Have consistent data units and geometric datum been used?	Yes	
2.8. Is there a clear description of the conceptual model?	No	What is in the model is described but the reasons for exclusions are not
2.8.1. Is there a graphical representation of the conceptual model?	No	
2.8.2. Is the conceptual model based on all available, relevant data?	No	
2.9. Is the conceptual model consistent with the model objectives and target model confidence level classification?	N/A	
2.9.1. Are the relevant processes identified?	No	
2.9.2. Is justification provided for omission or simplification of processes?	No	
2.10. Have alternative conceptual models been investigated?	No	
3. Design and construction		
3.1. Is the design consistent with the conceptual model?	No	
3.2. Is the choice of numerical method and software appropriate (Table 4-2)?	Yes	
3.2.1. Are the numerical and discretisation methods appropriate?	Yes	

Review Questions	Yes/ No	Comment
3.2.2. Is the software reputable?	Yes	
3.2.3. Is the software included in the archive or are references to the software provided?	Yes	
3.3. Are the spatial domain and discretisation appropriate?	No	
3.3.1. 1D/2D/3D	Yes	
3.3.2. Lateral extent	Yes	
3.3.3. Layer geometry?	No	
3.3.4. Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	Yes	
3.3.5. Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	No	
3.4. Are the temporal domain and discretisation appropriate?	?	
3.4.1. Steady state or transient	Yes	
3.4.2. Stress periods	?	
3.4.3. Time steps?	?	
3.5. Are the boundary conditions plausible and sufficiently unrestrictive?	No	
3.5.1. Is the implementation of boundary conditions consistent with the conceptual model?	?	
3.5.2. Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	No	
3.5.3. Is the calculation of diffuse recharge consistent with model objectives and confidence level?	N/A	
3.5.4. Are lateral boundaries time-invariant?	Yes	
3.6. Are the initial conditions appropriate?	Yes	
3.6.1. Are the initial heads based on interpolation or on groundwater modelling?	Yes	
3.6.2. Is the effect of initial conditions on key model outcomes assessed?	No	
3.6.3. How is the initial concentration of solutes obtained (when relevant)?	N/A	
3.7. Is the numerical solution of the model adequate?	Yes	
3.7.1. Solution method/solver	Yes	
3.7.2. Convergence criteria	No	
3.7.3. Numerical precision	No	
4. Calibration and sensitivity		
4.1. Are all available types of observations used for calibration?	No	
4.1.1. Groundwater head data	Yes	
4.1.2. Flux observations	No	
4.1.3. Other: environmental tracers, gradients, age, temperature, concentrations etc.	No	
4.2. Does the calibration methodology conform to best practice?	No	

Review Questions	Yes/ No	Comment
4.2.1. Parameterisation	No	
4.2.2. Objective function	No	
4.2.3. Identifiability of parameters	No	
4.2.4. Which methodology is used for model calibration?	Yes	
4.3. Is a sensitivity of key model outcomes assessed against?	No	
4.3.1. Parameters	Yes	But not fully
4.3.2. Boundary conditions	No	
4.3.3. Initial conditions	No	
4.3.4. Stresses	No	
4.4. Have the calibration results been adequately reported?	No	
4.4.1. Are there graphs showing modelled and observed hydrographs at an appropriate scale?	No	
4.4.2. Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	No	
4.4.3. Are calibration statistics reported and illustrated in a reasonable manner?	Yes	
4.5. Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?		
4.5.1. Spatially	No	
4.5.2. Temporally	No	
4.6. Are the calibrated parameters plausible?	No	
4.7. Are the water volumes and fluxes in the water balance realistic?	?	
4.8. Has the model been verified?	No	
5. Prediction		
5.1. Are the model predictions designed in a manner that meets the model objectives?	No	
5.2. Is predictive uncertainty acknowledged and addressed?	No	
5.3. Are the assumed climatic stresses appropriate?	?	
5.4. Is a null scenario defined?	No	
5.5. Are the scenarios defined in accordance with the model objectives and confidence level classification?	No	
5.5.1. Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	?	
5.5.2. Are well losses accounted for when estimating maximum pumping rates per well?	No	
5.5.3. Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	
5.5.4. Are the assumed stresses and timescale appropriate for the stated objectives?	?	
5.6. Do the prediction results meet the stated objectives?	No	
5.7. Are the components of the predicted mass balance realistic?	No	
5.7.1. Are the pumping rates assigned in the input files equal to the modelled pumping rates?	?	

Review Questions	Yes/ No	Comment
5.7.2. Does predicted seepage to or from a river exceed measured or expected river flow?	?	
5.7.3. Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g. evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	No	
5.7.4. Is diffuse recharge from rainfall smaller than rainfall?	Yes	Rainfall recharge is zero in the model
5.7.5. Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	
5.8. Has particle tracking been considered as an alternative to solute transport modelling?	N/A	
6. Uncertainty		
6.1. Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	No	
6.2. Is the model with minimum prediction-error variance chosen for each prediction?	Yes	
6.3. Are the sources of uncertainty discussed?	No	
6.3.1. Measurement of uncertainty of observations and parameters	No	
6.3.2. Structural or model uncertainty	No	
6.4. Is the approach to estimation of uncertainty described and appropriate?	No	
6.5. Are there useful depictions of uncertainty?	No	
7. Solute transport	N/A	
7.1. Has all available data on the solute distributions, sources and transport processes been collected and analysed?		
7.2. Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?		
7.3. Is the choice of numerical method and software appropriate?		
7.4. Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?		
7.5. Is there sufficient basis for the description and parameterisation of the solute transport processes?		
7.6. Are the solver and its parameters appropriate for the problem under consideration?		
7.7. Has the relative importance of advection, dispersion and diffusion been assessed?		
7.8. Has an assessment been made of the need to consider variable density conditions?		
7.9. Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?		
7.10. Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?		
7.11. Is the calibration based on meaningful metrics?		
7.12. Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?		
7.13. Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?		
7.14. Does the uncertainty analysis consider the effect of solute transport parameter		

Review Questions	Yes/ No	Comment
uncertainty, grid design and solver selection/settings?		
7.15. Does the report address the role of geologic heterogeneity on solute concentration distributions?		
8. Surface water–groundwater interaction		
8.1. Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	No	
8.2. Is the implementation of surface water–groundwater interaction appropriate?	No	
8.3. Is the groundwater model coupled with a surface water model?	No	
8.3.1. Is the adopted approach appropriate?	No	
8.3.2. Have appropriate time steps and stress periods been adopted?	?	
8.3.3. Are the interface fluxes consistent between the groundwater and surface water models?	N/A	

5.1. Is the Model fit for the purpose of groundwater allocation and management?

No, and in our opinion the DNRM (2000) model is overdue for a replacement. Our reasons include:

1. The conceptualisation of hydrogeology is presented in a section entitled “5.2 Model Conceptualisation” of DNRM (2000). In reality, this section appears to be a mix of hydrogeological conceptualisation and model building. This, in our experience, is not a good practise. Good modelling practise suggest a section on hydrogeological conceptualisation, followed by a description of model building, i.e. how the concepts were adopted in the model.
2. The system was conceptualised as a single layer system with no rainfall recharge or evaporation. Recharge from surface water to groundwater was overly simplified, but apart from several geological cross-sections, no data or information on recharge rates independent of the model were presented or referenced. No hydraulic parameters (for example from pumping tests) were presented; neither was an analysis of groundwater flow in both the horizontal and vertical sense provided.
3. The exclusion of the above features is important not just because the model report does not provide an adequate conceptual hydrogeology, but the features above may not subsequently be correctly translated to the model or not represented at all. The exclusion of underlying sandstones from the model and adaptation of a single-layer model, for example, appears to be driven by the lack of data and information (pages 20-21) not by sound concepts. The geological cross-sections presented in Figure 5a to 5d, if augmented by groundwater and surface water heads (or ranges of those), may have shown in places, such as beneath Lockyer Creek on Figure 5c, the potential for interaction between the creek and the sandstone. There appears to be a potential for rainfall recharge of the sandstones in the margins of all cross-sections and, in particular, beneath the sandstone hill covered by sands in Figure 5d. In addition, DNRM (2000) assumed that recharge occurs from surface water to groundwater at all stress periods and reaches of the creeks. In our experience, the interaction between surface and groundwater is complex and often dynamic; also often adjoining reaches may recharge and receive groundwater at a given time.
4. Because a one-layer model was adopted, the clays, between the alluvium and the land surface, are not presented at all and therefore the surface watercourses would also ‘float’ above the model, i.e. cannot be simulated by the RIVER package in the one-layer model adopted by DNRM (2000). The resultant simulation of surface water recharge to groundwater by recharge cells is calculated outside the model and is not transparent.
5. The lack of transparency in model documentation and in model building appears to affect the entire documentation. There is a general absence of data and facts and referencing the presumably large amount of work that has been completed prior to the modelling. There are only three publications listed in the references section, two of which refer to modelling software.

6. There is an absence of data and information known prior to the model construction relating to rainfall recharge, hydraulic parameters, published quantitative evidence for surface water – groundwater interaction; and the analysis of groundwater flow in both the horizontal and vertical sense (with the exception of groundwater head maps at selected times aiding the setting of fixed-head boundary cells. Because of the absence of facts, the conceptual hydrogeology and the model are built on concepts that may or may not be correct – there is little information presented or referenced to make a judgment.

5.2. The confidence in modelling outputs, uncertainties and/or limitations in modelling data inputs, assumptions, model set-up and overall technical approach.

We have little confidence in the model solution presented in DNRM (2000). The model solution presented in DNRM (2000), DNRM (2018) and DES (2018) are all based on the DNRM (2000) model and in our view, represent one of the many possible solutions in terms of a combination of recharge, extraction and groundwater heads, that 'calibrate' to the observed groundwater heads.

1. The absence of hydraulic data prior to modelling suggests that realistic parameter constraints or bounds could not be established, and hydraulic parameters had to be estimated from model calibration in Stage 1. The effects can be seen in Figure 15 that indicates the existence of zones with straight, unnatural looking boundaries and some zones with huge contrast in adjoining hydraulic conductivity: 250 m/day vs 5 m/day or 7.5 m/day and 143 m/day vs 3 m/day. It is difficult to comprehend how such alluvial system has developed and how these contrasts, the results of model error minimisation, can be justified.
2. The model RMS errors, around 1m in DNRM (2000) represent a reasonable fit to observed groundwater heads but are generated by, in our opinion, an over-constrained model. Fixed head cells, as the name suggests, tie the groundwater head at both upstream and downstream ends of the model, and in our opinion, heads within the model domain area overly constrained in a long and narrow alluvium such as DNRM (2000). The model would interpolate between the upstream and downstream end with limited freedom to alter those locally due to local recharge/extraction. In addition, the model relies on local calibration, reflected by the 53 hydraulic and 34 recharge zones used. These are too many in our experience.
3. Ultimately, an incomplete conceptual hydrogeology means an incomplete model. It is important to note that although the model calibration errors are small, around 1 m RMS, the model solution provided is based on a water balance that appears to be overwhelmingly dominated by surface water recharge and groundwater extraction. The sensitivity analysis provided for each stage in DNRM (2000) involves varying the hydraulic parameters only and no uncertainty analysis is offered. In our view, if recharge and/or extraction were altered, they would have generated a different set of 'calibrated' hydraulic parameters, with similar or somewhat higher RMS errors than those presented in DNMR (2000).
4. The lack of transparency in model documentation and in model building appears to affect the entire documentation. There is a general absence of data and facts and referencing the presumably large amount of work that has been completed prior to the modelling. There are only three publications listed in the references section in DNRM (2000), two of which refer to modelling software.

5.3. Key issues and factors relevant to the hydrologic performance of the Central Lockyer groundwater system.

The key issues for the Central Lockyer groundwater system, with respect to numerical modelling are:

- Does the conceptual hydrogeology capture all important factors?
- Uncertainty in recharge and extraction may have a disproportionate effect on calibration.

Question 1 was already answered with a “no” in Section 5.1.

With regard to uncertainties, the DNRM (2000) model solution provided is based on a water balance that appears to be overwhelmingly dominated by surface water recharge and groundwater extraction. While we agree that those are most important features in the Central Lockyer Valley, we are uncertain if their domination is as strong as suggested by DNRM (2000). Rainfall recharge and evaporation, and interaction between the alluvium and sandstone, are not represented in the model but may exist, reducing the dominance of extraction and recharge.

Notwithstanding the above, the key issue for the DNRM (2000) groundwater model is that a small change in the dominant factors in the model may cause a large change in the ‘calibrated’ hydraulics. As the hydraulic parameters were not known prior to modelling, they were calculated from the model during Stage 1. If the extraction and/or recharge carry a moderate uncertainty, the hydraulic parameters required to reduce the RMS error may be too large. If, for example, extraction is higher in reality than what is modelled, the model calibration will compensate by changing the hydraulic parameters and boundary conditions, sometimes beyond values considered reasonable. We suspect that is the case for the upper end of hydraulic conductivities presented in Figure 15 of DNRM (2000). The ‘incorrect’ hydraulic conductivities are next carried to Stage 2 and are compensated for by assigning incorrect recharges from surface water.

The sensitivity analysis provided for each stage in DNRM (2000) involved varying the hydraulic parameters only. In our view, if recharge and/or extraction were altered, they would have generated a different set of ‘calibrated’ hydraulic parameters, with similar or somewhat higher RMS errors than those presented in DNMR (2000). In our experience, it is better to maintain a realistic range of parameters and put up with larger errors than to focus on decreasing errors.

5.4. Recommendations

We suggest that the DNRM (2000) model is overdue for a replacement and recommend a modelling programme that is transparent for stakeholders and water users such as the Lockyer Water Users Forum. This programme should include the following tasks:

1. prior to modelling, collate data and information on creek and lake water elevations and flows, creek and lake bed elevations and groundwater heads, each as space and time-dependent variables;
2. prior to modelling establish a dataset that includes metered and estimated groundwater extraction per bore as time-series and assign confidence/uncertainty to each bore and time of measurement;
3. prior to modelling establish a dataset on hydraulic parameters, test-types, the lengths of test and accompanying confidence/uncertainty;
4. prior to modelling, define the conceptual hydrogeology and consider the inclusion of irrigation return water; and
5. prior to modelling, establish a dataset on any other aspects identified in the conceptual hydrogeology i.e. geometry of layers to be modelled, rainfall recharge, model evaporation and extinction depth.

Once the above tasks are completed and published (or reported in a Queensland government report) the modelling could commence. The process recommended above would ensure that inputs to the model are collated (as opposed to interpreted) prior to model building.

We cannot, at this stage, recommend field work for the Lockyer Water Users Forum. We believe it would be irresponsible at present to recommend field work without establishing first what data and information are available.

6. References

Barnett B, Townley LR, Post V, Evans RE, Hunt RJ, Peeters L, Richardson S, Werner AD, Knapton A and Boronkay A. (2012) Australian groundwater modelling guidelines, Waterlines report, National Water Commission, Canberra.

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Department of Natural Resources & Mines. (2000). Central Lockyer Groundwater Model. Groundwater Model Report. Water Assessment NRS – RC&T Natural Resource Sciences, 80 Meiers Rd, Indooroopilly, Qld 4068. Department of Natural Resources & Mines.

Department of Natural Resources & Mines. (2018). Central Lockyer Valley water supply scheme benefitted groundwater area. Technical report for the Moreton Water Plan amendment, November 2018. Water Services South Region, Department of Natural Resources and Mines. © State of Queensland, 2018.

Appendix A PowerPoint presentation delivered to the Lockyer Water Users Forum on the 18 January 2019

High-level Review of the Central Lockyer Groundwater Model

Prepared for

Lockyer Water Users Forum

By

Daniel Barclay and Gabor Bekesi

18 January 2018

hydrogeologist.com.au

Objectives

- Is the Model fit for the purpose of groundwater allocation and management?
- The confidence in modelling outputs, uncertainties and/or limitations in modelling data inputs, assumptions, model set-up and overall technical approach.
- Key issues and factors relevant to the hydrologic performance of the Central Lockyer groundwater system.
- Responses to irrigators' views, concerns, insights and questions in relation to the above.

Reports reviewed

- DNRM, Department of Natural Resources & Mines. (2000). Central Lockyer Groundwater Model. Groundwater Model Report.
- DNRM, Department of Natural Resources & Mines. (2018). Central Lockyer Valley water supply scheme benefitted groundwater area.
- DES, Department of Environment and Science. (2018). Central Lockyer groundwater model scenario. Prepared for Department of Natural Resources.

Structure of our draft report

- In sections 2-4, we provide a summary and the important issues identified through the review for each of DNRM (2000), DNRM (2018) and DES (2018), respectively.
- Sections 5 contains our conclusions and recommendations, including our answers to the questions raised by the Lockyer Water Users Forum.

Comment:

In reviewing DNRM (2000), some of the comments refer to model development. At the time of the model development (through the 1990s), software and hardware were inferior to those available at present. We provide our comments as if the model was created recently as we understand that the proposed water allocation in the Central Lockyer Valley is based on DNRM (2000).

Conclusions

1. Is the Model fit for the purpose of groundwater allocation and management?

No, and in our opinion the DNRM (2000) model is overdue for a replacement.

2. The confidence in modelling outputs, uncertainties and/or limitations in modelling data inputs, assumptions, model set-up and overall technical approach.

We have little confidence in the model solution presented in DNRM (2000). The model solution presented in DNRM (2000), DNRM (2018) and DES (2018) are all based on the DNRM (2000) model and in our view, represent one of the many possible solutions in terms of a combination of recharge, extraction and groundwater heads, that 'calibrate' to the observed groundwater heads.

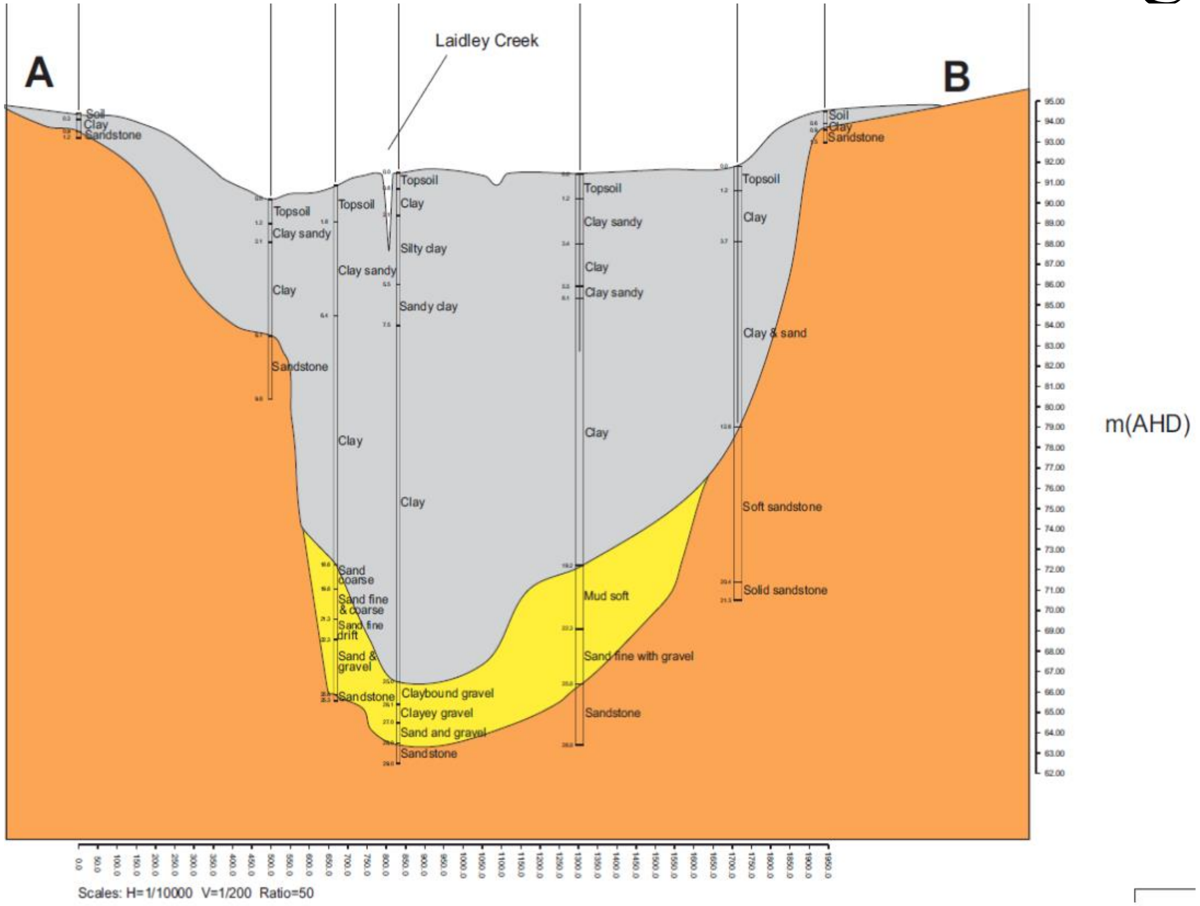
3. Key issues and factors relevant to the hydrologic performance of the Central Lockyer groundwater system.

The key issues for the Central Lockyer groundwater system, with respect to numerical modelling are:

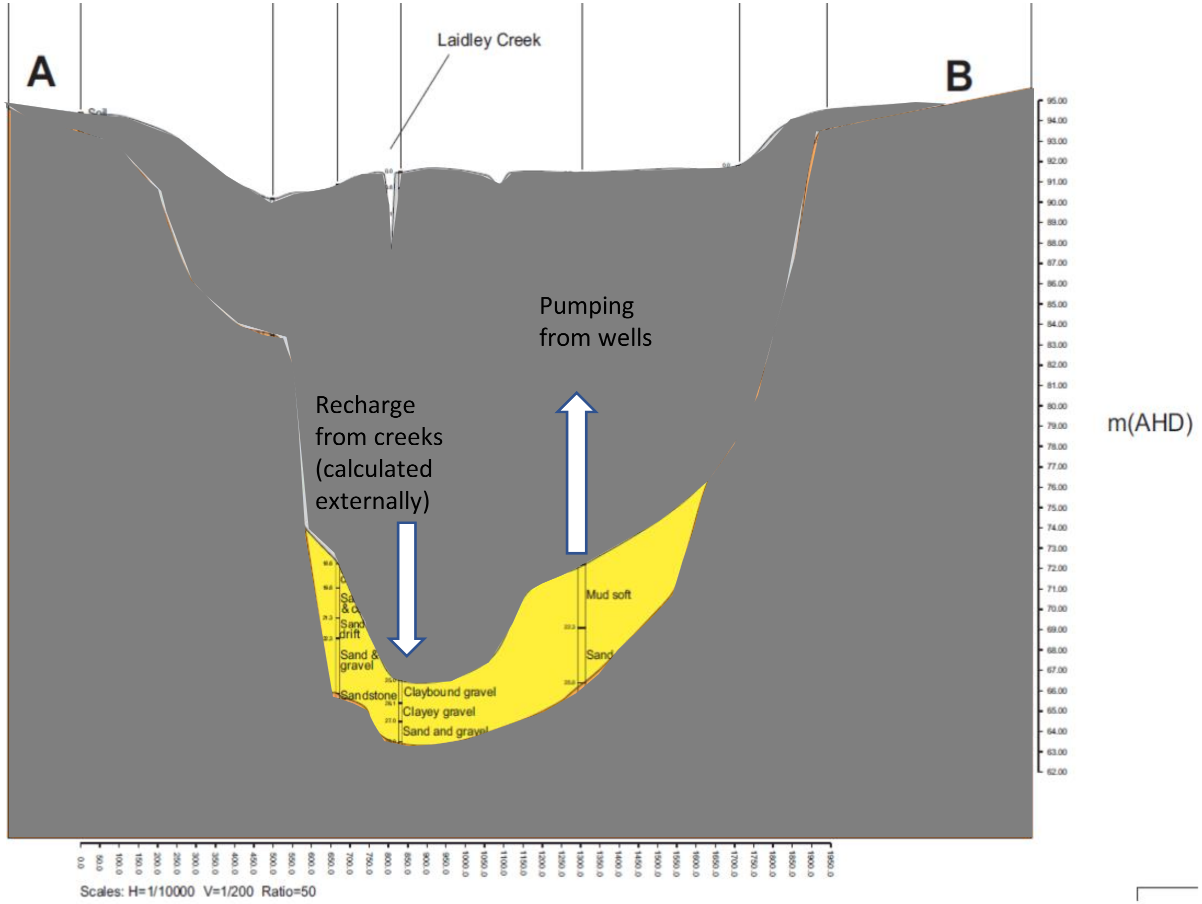
- The conceptual hydrogeology for the model does not capture all important factors.
- Uncertainty in recharge and extraction may have a disproportionate effect on calibration.

The DNRM (2000) model solution provided is based on a water balance that appears to be overwhelmingly dominated by surface water recharge and groundwater extraction. While we agree that those are most important features in the Central Lockyer Valley, we are uncertain if their domination is as strong as suggested by DNRM (2000). Rainfall recharge and evaporation, and interaction between the alluvium and sandstone, are not represented in the model but may exists in reality reducing the dominance of extraction and recharge.

Is the Model fit for the purpose of groundwater allocation and management?



Is the Model fit –concepts used in the model

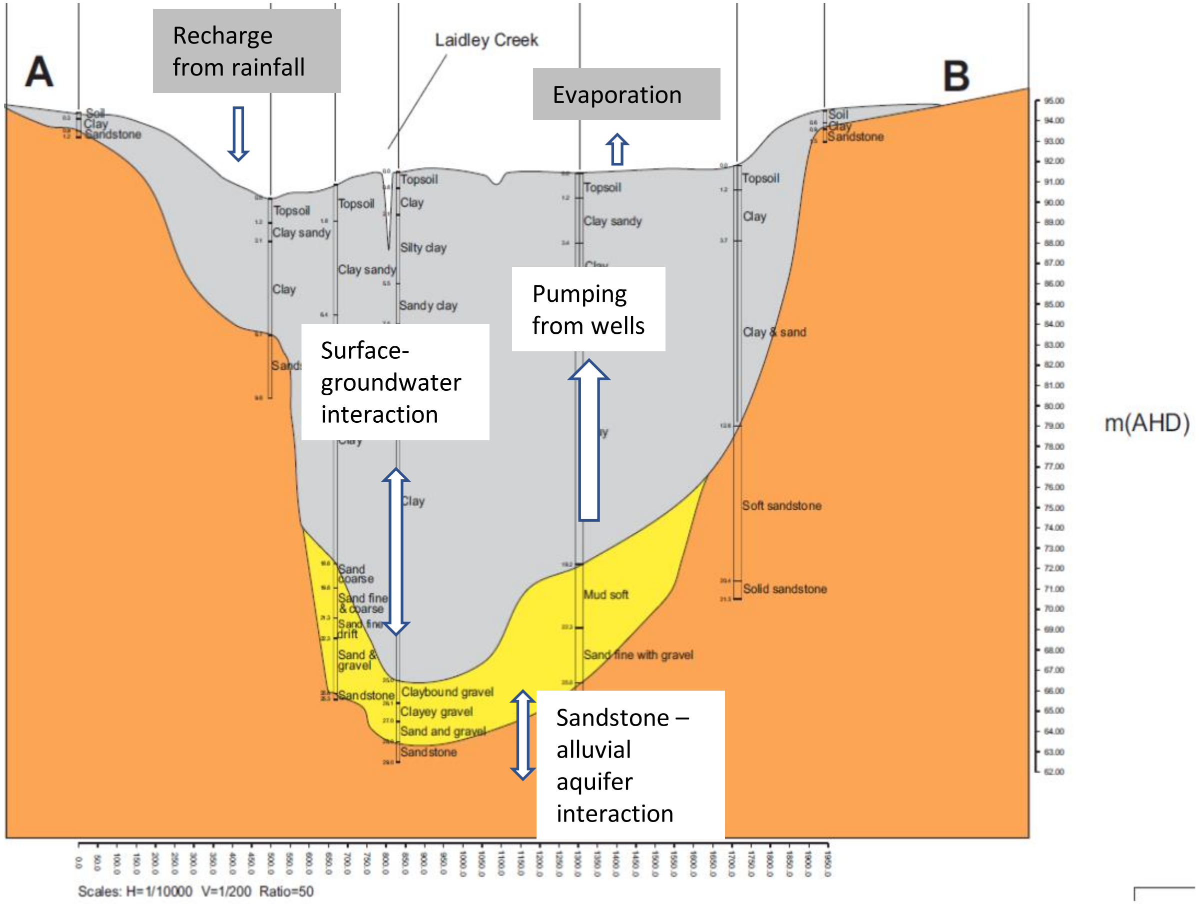


Pumping from wells

Recharge from creeks (calculated externally)

The system was conceptualised as a single layer system with no rainfall recharge or evaporation. Recharge from surface water to groundwater was overly simplified.

Hydrogeological setting



Recharge from rainfall

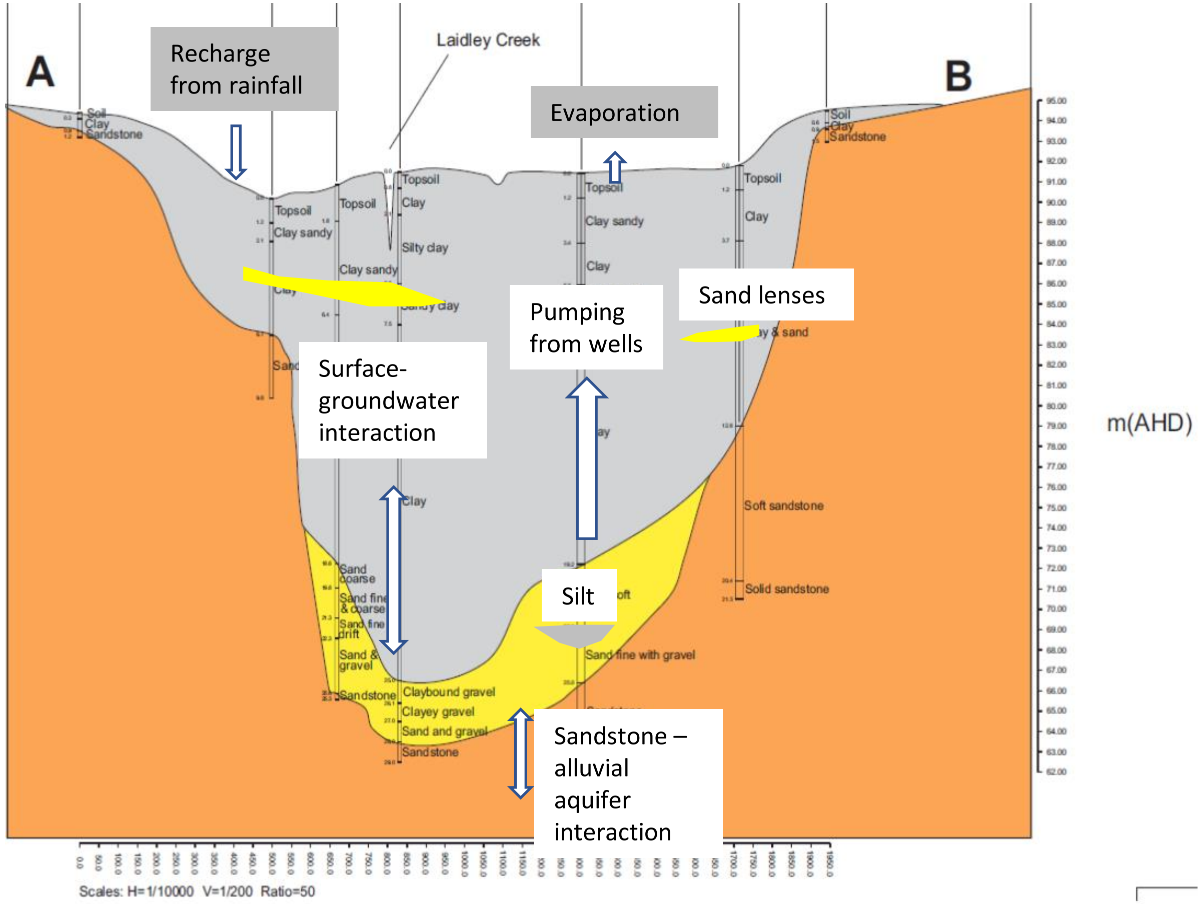
Evaporation

Pumping from wells

Surface-groundwater interaction

Sandstone – alluvial aquifer interaction

A more complex alternative



We understand that KBR (2003) addressed complexities and inhomogeneities in the alluvium.

The geological interpretation may be restricted by limitations in strata description.

The confidence in modelling outputs, uncertainties and/or limitations in modelling data inputs

We have little confidence in the model solution presented in DNRM (2000). The model solution presented DNRM (2018) and DES (2018) are all based on the DNRM (2000) model and in our view, represent one of the many possible solutions in terms of a combination of recharge, extraction and groundwater heads, that ’calibrate’ to the observed groundwater heads.

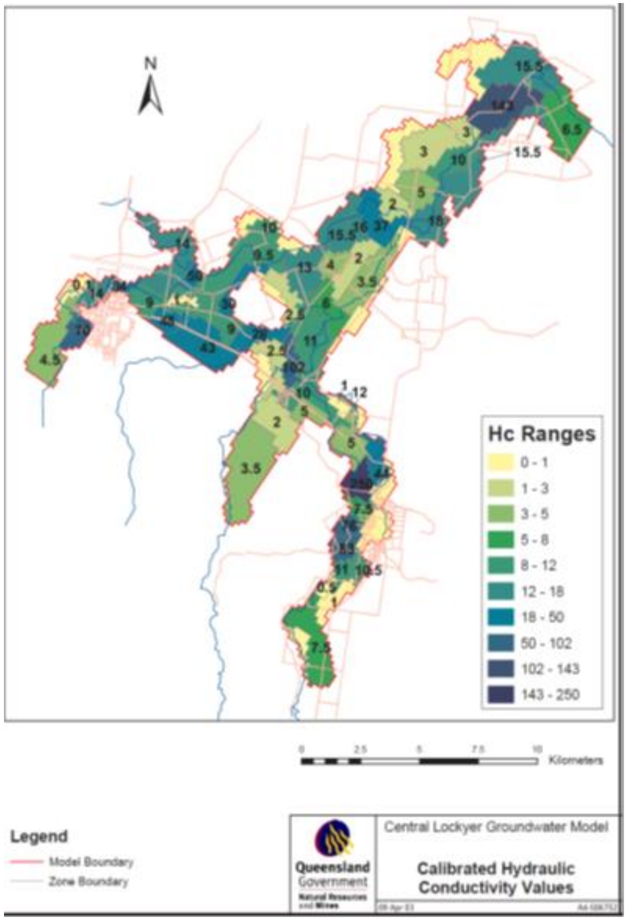
- An incomplete conceptual hydrogeology means an incomplete model. The model solution provided is based on a water balance that appears to be overwhelmingly dominated by surface water recharge and groundwater extraction.
- The sensitivity analysis provided for each stage in DNRM (2000) involves varying the hydraulic parameters only and no uncertainty analysis is offered. In our view, if recharge and/or extraction were altered, they would have generated a different set of ‘calibrated’ hydraulic parameters, with similar or somewhat higher RMS errors than those presented in DNRM (2000).
- The lack of transparency in conceptualisation and development appears to affect the entire documentation. There is a general absence of data and facts, and referencing the presumably large amount of work that has been completed prior to the modelling. There are only three publications listed in the references section in DNRM (2000), two of which refer to the modelling software used.

The confidence in modelling cont'd

The absence of hydraulic data prior to modelling suggests that realistic parameter constraints or bounds could not be established and hydraulic parameters had to be estimated from model calibration in Stage 1.

The effects can be seen in Figure 15 that indicates the existence of zones with straight, unnatural looking boundaries and some zones with huge contrast in adjoining hydraulic conductivity: 250 m/day vs 5 m/day or 7.5 m/day and 143 m/day vs 3 m/day.

It is difficult to comprehend how such an alluvial system has developed and how these contrasts, the results of model error minimisation, can be justified.



Does the conceptual hydrogeology capture all important factors?

No

- The DNRM (2000) model solution provided is based on a water balance that appears to be overwhelmingly dominated by surface water recharge and groundwater extraction.
- While we agree that those are most important features in the Central Lockyer Valley, we are uncertain if their domination is as strong as suggested by DNRM (2000).
- Rainfall recharge, evaporation and interaction between the alluvium and sandstone, are not represented in the model but may exists in reality reducing the dominance of extraction and recharge.

Uncertainty in recharge and extraction may have a disproportionate effect on calibration

A small change in the dominant factors in the DNRM (2000) model (extraction and recharge from creeks) may cause a large change in the 'calibrated' hydraulics.

As the hydraulic parameters were not known prior to modelling, they were calculated from the model during Stage 1. If the extraction and/or recharge carry a moderate uncertainty (which we believe they do), the hydraulic parameters required to reduce the RMS error may be unrealistic.

If, for example, extraction is higher in reality than what is modelled, the model calibration will compensate by changing the hydraulic parameters and boundary conditions, sometimes beyond values considered reasonable. We suspect that is the case for the upper end of hydraulic conductivities presented in Figure 15 of DNRM (2000). The incorrect hydraulic conductivities are next carried to Stage 2, and are compensated for by assigning incorrect recharge from surface water. The end result is a model that is 'calibrated' but unrealistic.

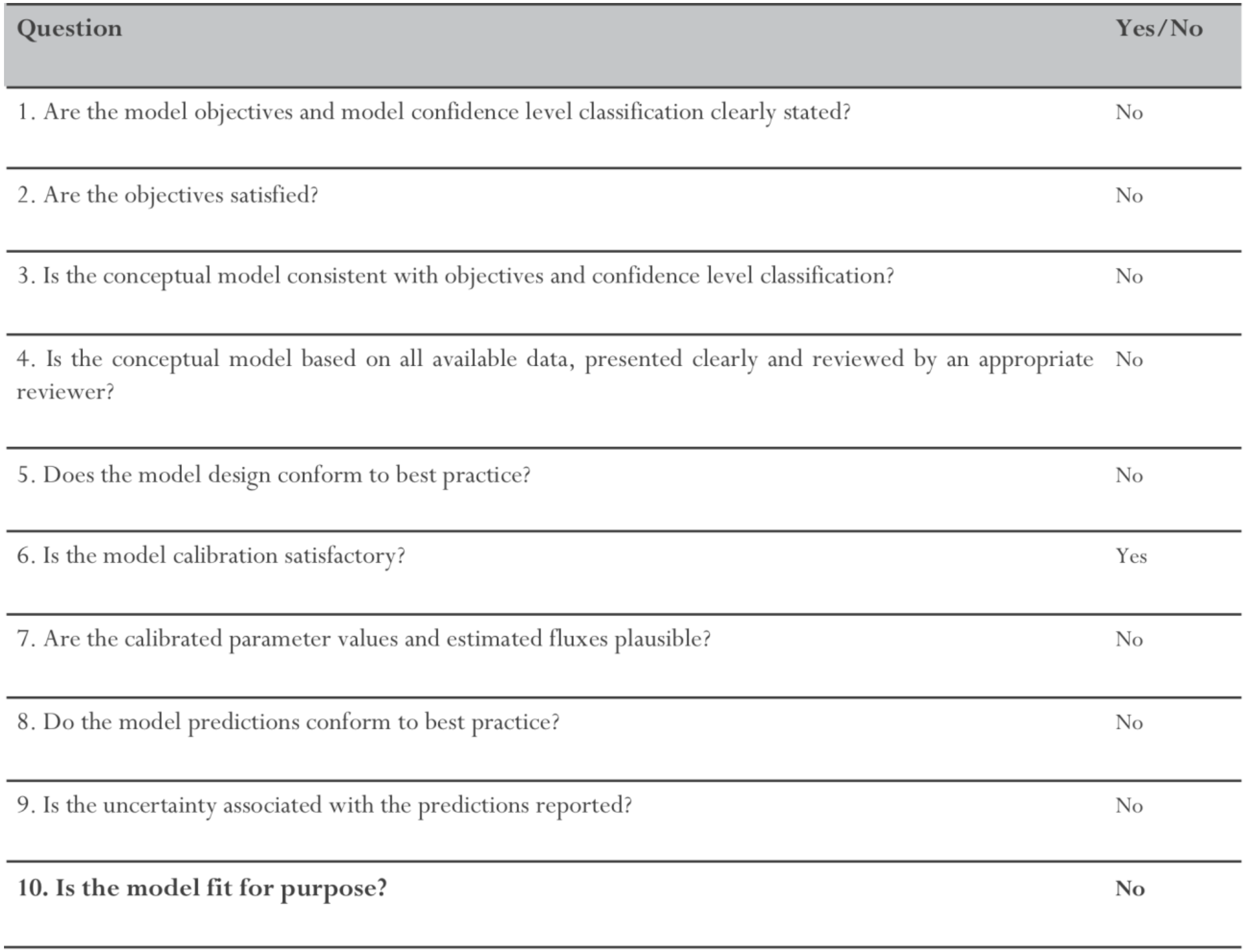
Uncertainty in recharge and extraction may have a disproportionate effect on calibration

The sensitivity analysis provided for each stage in DNRM (2000) involved varying the hydraulic parameters only.

In our view, if recharge and/or extraction were altered, they would have generated a different set of 'calibrated' hydraulic parameters, with similar or somewhat higher errors than those presented in DNMR (2000).

In our experience, it is better to maintain a realistic range of parameters and put up with larger errors than to focus on decreasing errors by adopting unrealistic parameter values.

Compliance checklist from Barnett *et al*. (2012)



Question	Yes/No
1. Are the model objectives and model confidence level classification clearly stated?	No
2. Are the objectives satisfied?	No
3. Is the conceptual model consistent with objectives and confidence level classification?	No
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	No
5. Does the model design conform to best practice?	No
6. Is the model calibration satisfactory?	Yes
7. Are the calibrated parameter values and estimated fluxes plausible?	No
8. Do the model predictions conform to best practice?	No
9. Is the uncertainty associated with the predictions reported?	No
10. Is the model fit for purpose?	**No**

Recommendations

We suggest that the DNRM (2000) model is overdue for a replacement and recommend a modelling programme that is transparent for stakeholders and water users such as the Lockyer Water Users Forum. This programme should include the following tasks:

- Prior to modelling, collate data and information on creek and lake water elevations and flows, creek and lake bed elevations and groundwater heads, each as space and time-dependent variables;
- Prior to modelling establish a dataset that includes metered and estimated groundwater extraction per bore as time-series and assign confidence/uncertainty to each bore and time of measurement;
- Prior to modelling establish a dataset on hydraulic parameters, test-types, the lengths of test and accompanying confidence/uncertainty;
- Prior to modelling, define the conceptual hydrogeology; and,
- Prior to modelling, establish a dataset on any other aspects identified in the conceptual hydrogeology ie geometry of layers to be modelled, rainfall recharge, irrigation return water, model evaporation and extinction depth.

We cannot, at this stage, recommend field work for the Lockyer Water Users Forum. We believe it would be irresponsible at present to recommend field work without establishing first what data and information are available.