Groundwater numerical modelling for the Gippsland Basin bioregion

Product 2.6.2 from the Gippsland Basin Bioregional Assessment

2018

2.6.2.2.1 Introduction

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment

The Office of Water Science, within the Australian Government Department of the Environment, is strengthening the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice about the potential water related impacts of those developments. For more information, visit http://www.environment.gov.au/coal-seam-gas-mining/.

Bureau of Meteorology

The Bureau of Meteorology is Australia's national weather, climate and water agency. Under the *Water Act 2007*, the Bureau is responsible for compiling and disseminating Australia's water information. The Bureau is committed to increasing access to water information to support informed decision making about the management of water resources. For more information, visit http://www.bom.gov.au/water/.

Department of Environment, Land, Water and Planning

The Department of Environment, Land, Water and Planning creates liveable, inclusive and sustainable communities that support jobs and growth in Victoria. We recognise the link between the built and natural environment in the quality of our lives, and work to accommodate population growth while maintaining world class liveability and protecting our heritage for future generations. For more information, visit http://www.delwp.vic.gov.au.

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Department of Economic Development, Jobs, Transport and Resources

Agriculture Victoria works with the agriculture and fisheries industries on research, development and extension to improve production, connect the sector with international markets, support development and maintain effective biosecurity controls. For more information, visit http://agriculture.vic.gov.au

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Cover photograph

Lake Victoria, Victoria, 2013

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2.6.2 Groundwater numerical modelling for the Gippsland Basin bioregion

This product presents the modelling of groundwater quantity and availability within the Gippsland Basin subregion or bioregion. It describes:

- the modelling undertaken
- results for hydrological response variables identified in the conceptual model of causal pathways (product 2.3)
- connections with surface water
- limitations of the analysis.

Coal and coal seam gas development can potentially affect assets and receptors (either negatively or positively) through direct, indirect or cumulative impacts on groundwater hydrology. An assessment of these impacts on receptors in the Gippsland Basin bioregion has not been undertaken as part of the Gippsland Basin Bioregional Assessment, as per the revised Schedule with the Office of Water Science in 2015.

2.6.2.1 Methods

Summary

The bioregional assessment of the Gippsland Basin was based on results derived using a combination of a detailed multi-layered regional groundwater model and a catchment runoff model. This modelling approach was similar to the methodology adopted for the onshore natural gas water science study commissioned by the Victorian Department of Environment, Land, Water and Planning.

The catchment runoff model simulated the quickflow component of streamflow, calculated as the sum of runoff and sub-surface later flows, whereas the regional groundwater model simulated the groundwater baseflow contribution to streamflow. The total streamflow impact was the sum of these quickflow and baseflow contributions. The regional groundwater model also simulated the groundwater level within regions of interest.

The difference in simulated streamflow and groundwater level between a baseline condition and future expanded Coal resource development pathway of open-cut coal mine operations was evaluated and used to estimate the impact of the coal resource development pathway on groundwater dynamics and interactions with surface features.

A review of coal resource development pathways (CRDPs) in the Gippsland Basin, as outlined in technical product 2.3, identified three proposed developments from which model scenarios could be evaluated based on the continued expansion of the Yallourn, Hazelwood and Loy Yang open-cut coal mines. This review formed the context and construct of the modelling methodology and identified that large coal mining development has the potential to directly affect the regional groundwater system and that coal mine development can potentially affect assets and receptors (either negatively or positively) through a direct, indirect or cumulative impact on groundwater hydrology. Any impact on the groundwater systems in connection with the shallow alluvium aquifers has the potential to affect streamflow (and therefore surface water resources) within the Latrobe River basin in which the open-cut coal mines are located. Given the proximity of the Yallourn coal mine to the Latrobe River, and the Hazelwood coal mine to the Morwell River, it is anticipated that expanded open-cut coal mine operations will reduce runoff and groundwater baseflow which has the potential to affect streamflow directly.

The river networks within the Gippsland Basin are highly regulated. Numerous existing complex river routing models are used to inform surface water management. Explicit models exist for the Latrobe, Thomson, Mitchell and Avon rivers which account for diversion, releases and bypass flows. It was considered that the modelling of river management, or the routing of streamflow through the river networks, using the suite of existing river models was not necessary as the salient features of streamflow can be simulated solely using the combination of a catchment runoff model (to predict quickflow impacts) and a distributed groundwater model (to predict baseflow impacts).

A model, or model sequence, is needed that can simulate the impact of the coal resource development pathway upon the identified regional groundwater system and the stream network.

Developing a single, coupled and integrated surface water and groundwater model is beyond the scope of this assessment. Therefore, for the bioregional assessment of the Gippsland Basin, a combination of two predictive numerical models were utilised consisting of a regional multi-layered groundwater model and a catchment runoff model. The modelling approach was based on the methodology adopted for the onshore natural gas water science study commissioned by the Department of Environment, Land, Water and Planning (Beverly et al., 2015).

The catchment runoff model adopted in the study was the Catchment Analysis Tool (CAT) (Beverly et al., 2005; Beverly, 2009) which comprises a suite of farming system models to estimate daily water balances. The CAT model simulates farm management units linked within a catchment framework with allowance for landscape connectivity and connection to a distributed, multi-layered groundwater model. The farm-scale models account for position in the landscape (topography, soil type, aspect and slope), climate, land use and land management and simulates water balance, nutrient transport and vegetative production on a daily time step. Daily recharge and evapotranspiration estimates from this model were used as inputs into the underlying distributed groundwater model.

The regional distributed groundwater model was based on MODFLOW-2005. This model was developed to simulate (1) the change in drawdown on economic receptors (groundwater bores) and ecological receptors (groundwater-dependent ecosystems); (2) the change in groundwater level within regions of interest; and (3) the change in surface water – groundwater flux. The predicted surface discharge flux from groundwater was then coupled with runoff and sub-surface lateral flow estimates derived from the CAT to predict total streamflow.

In the baseline model the impact of the existing coal mines (as defined by current extent and extractions) and their future closure pathways are simulated under modified climate conditions. The CRDP simulation includes the continued expansion of the Yallourn, Hazelwood and Loy Yang open-cut coal mines in accordance with mine planning proposals until mine closure. Both the baseline and CRDP mine closure dates are the same. The difference between the baseline and CRDP simulated streamflow and groundwater drawdowns is known as the additional coal resource development (ACRD). The changes in streamflow and groundwater drawdown simulated under the ACRD are used to estimate the potential impact of the coal resource development pathway on the economic and ecological receptors within the reporting regions of interest. The details of the implementation of the CRDP are documented in Section 2.6.2.2.5 and includes an outline of the future climate change signal used to generate the daily modified climate conditions. The total streamflow impact between the baseline and coal resource development pathway conditions is calculated as the sum of the difference in the CAT simulated contribution to stream (defined as the sum of runoff and sub-surface lateral flows) and the MODFLOW-2005 simulated baseflow for each scenario. The time series of streamflow difference are summarised in a number of hydrologically relevant zones and the primary surface water receptor identified as the Latrobe River.

A comprehensive outline of the technical detail of the conceptualisation, parameterisation and CRDP implementation are documented in Section 2.6.2. Sensitivity analysis was undertaken to assess the impact of varying selected model input parameters on key modelled outputs. However, due to the complexity of the modelling framework, uncertainty analyses were not undertaken.

2.6.2.2 Review of existing models

Summary

A review of the existing groundwater management tools developed for the Gippsland Basin (SKM 2011a) commissioned by the then Victorian Department of Sustainability and Environment (DSE) identified 18 pre-existing groundwater models, ranging in complexity from impact assessment frameworks to distributed physics-based numerical models. Subsequent to this review, the DPI Gippsland Basin Model (Beverly et al., 2012) was developed based on the IRM Gippsland Basin model (Schaeffer, 2008). More recently, the CSIRO has developed a Latrobe Valley Coal Model (LVCM) to assess the likely water management issues associated with potential coal seam gas extractions in the Latrobe Valley (Freij-Ayoub et al., 2011a). The most recent regional groundwater model was developed for the Victorian Onshore Natural Gas Water Science Studies (VWSS) to assess the potential impacts of future onshore gas extractions and to understand the possible impacts of a potential onshore natural gas industry on groundwater and surface waters within the Gippsland region. This document summarises the key attributes of each model and has identified that the most recent regional groundwater model has the required spatial extent, vertical resolution and model grid to evaluate the bioregional assessment.

2.6.2.2.1 Introduction

A review of the existing groundwater management tools developed for the Gippsland Basin (SKM, 2011a) commissioned by the then Victorian Department of Sustainability and Environment (DSE) identified 18 models ranging in complexity from impact assessment frameworks to distributed physics-based numerical models. The models reviewed were:

- Stage 1 (Fraser, 1980) and review of Stage 1 report (Golder Associates, 1990)
- Stage 2 (Evans, 1983)
- Stage 3 (Bolger, 1987)
- Reservoir simulation of the Gippsland Basin (Henzell et al., 1985)
- Loy Yang (Bolger, 1990; Golder Associates, 1990)
- Latrobe Valley Resource Model — Update (Golder Associates, 1991)
- Latrobe Valley Resource Model — Update (Golder Associates, 1992a)
- Latrobe Valley Resource Model — Update (Golder Associates, 1992b)
- Latrobe Valley Resource Model — Update (Golder Associates, 1992c)

- Stage 4 (GeoEng, 1994)
- Stage 5 (GeoEng, 1996a)
- Gippsland Basin (SKM, 1995)
- Gippsland Basin (SKM, 1996)
- Yarram sub-regional model (SKM, 1999)
- Gippsland Basin (Nahm, 2002)
- Sale WSPA Groundwater Model (SKM, 2011a)
- Integrated Resource Model (IRM) of the Gippsland Basin (Schaeffer, 2008)
- ecoMarkets (GHD, 2008; 2010a; 2010b; 2010c).

Subsequent to the SKM review, the CSIRO developed a Latrobe Valley Coal Model (LVCM) to assess the likely water management issues associated with potential coal seam gas extractions in the Latrobe Valley (Freij-Ayoub et al., 2011a) and the DPI Gippsland Basin Model (Beverly et al., 2012) was developed to assess the long-term, equilibrium impacts of likely coal seam gas extractions and expanded open cut mining activity on aquifer potentiometric surfaces. The DPI Gippsland Basin Model was based in part on the IRM Gippsland Basin model (Schaeffer, 2008). At the time of this study, the most recent regional groundwater model was that utilised for the Victorian Onshore Natural Gas Water Science Studies (VWSS) to assess the potential impacts of future onshore gas developments and to understand the possible impacts of a potential onshore natural gas industry on groundwater and surface waters within the Gippsland region (Beverly et al., 2015). Summarised below are the key features of those models considered to have sufficient extent, grid resolution, design focus and attribution relevant to this study.

2.6.2.2.2 Review of the Integrated Resource Model

The Integrated Resource Model (IRM) was developed by Schaeffer (2008) to simulate the impacts of different groundwater abstractions and multiple pumping and artificial recharge scenarios on groundwater levels within the Gippsland Basin. The model represented 18 layers comprising the unconfined surface layer, the basement layer, eight regional aquifers and eight regional aquitards, as shown in Figure 1. Time dependent general head boundaries were assigned to the eastern and southern regions of the model domain, with no flow boundaries assigned to the western and northern regions of the model, as shown in Figure 2 and

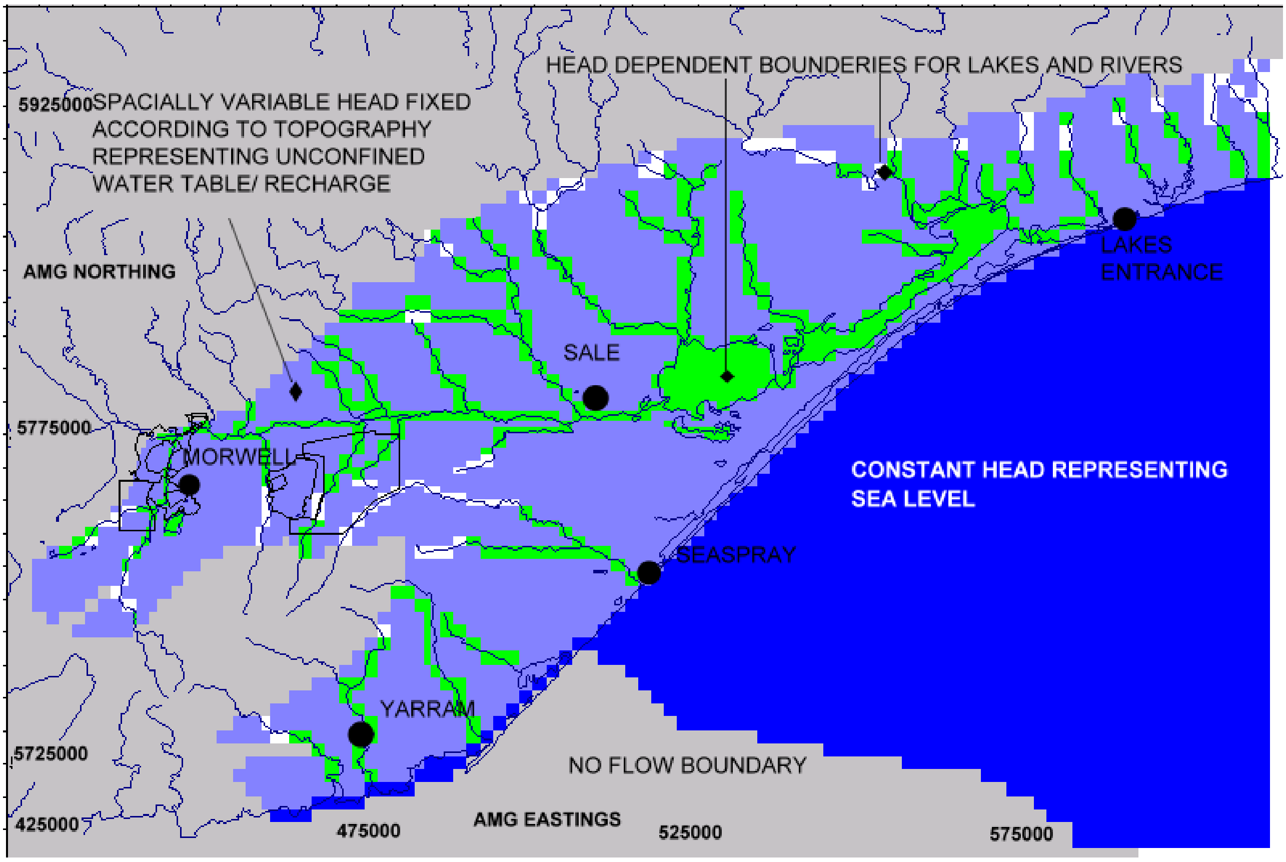


Figure 3. Spatially variable hydraulic conductivities were assigned based on lithological analysis and structural regions. Recharge was assigned to sub-cropping aquifers and groundwater extractions were incorporated to account for offshore pumping, coal mine dewatering and irrigation in the Yarram region.

Calibration of this model was based on matching simulated heads and groundwater trends with observation bore data from 1960 to 1999. The error criterion was 10 m with model validation based on data from 2000 to 2004.

The recommendations for future improvement of this model as reported by SKM (2011a) included improved calibration of the unconfined aquifer, refinement of the recharge input and extension of the eastern and southern boundaries to reduce boundary-induced effects when assessing the impacts of artificial recharge and pumping adjacent to these boundaries.

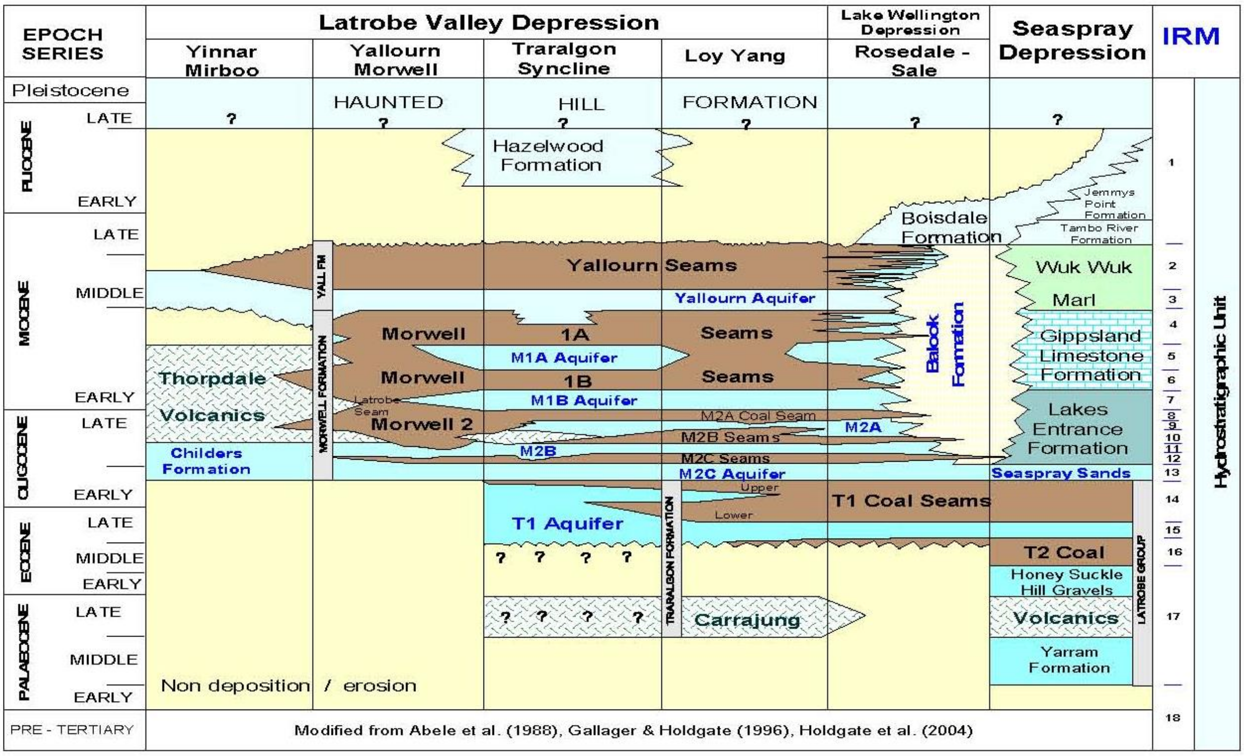


Figure 1 **Grouping of hydrostratigraphic units incorporated into the IRM model layer structure (sourced from Schaeffer 2008)**

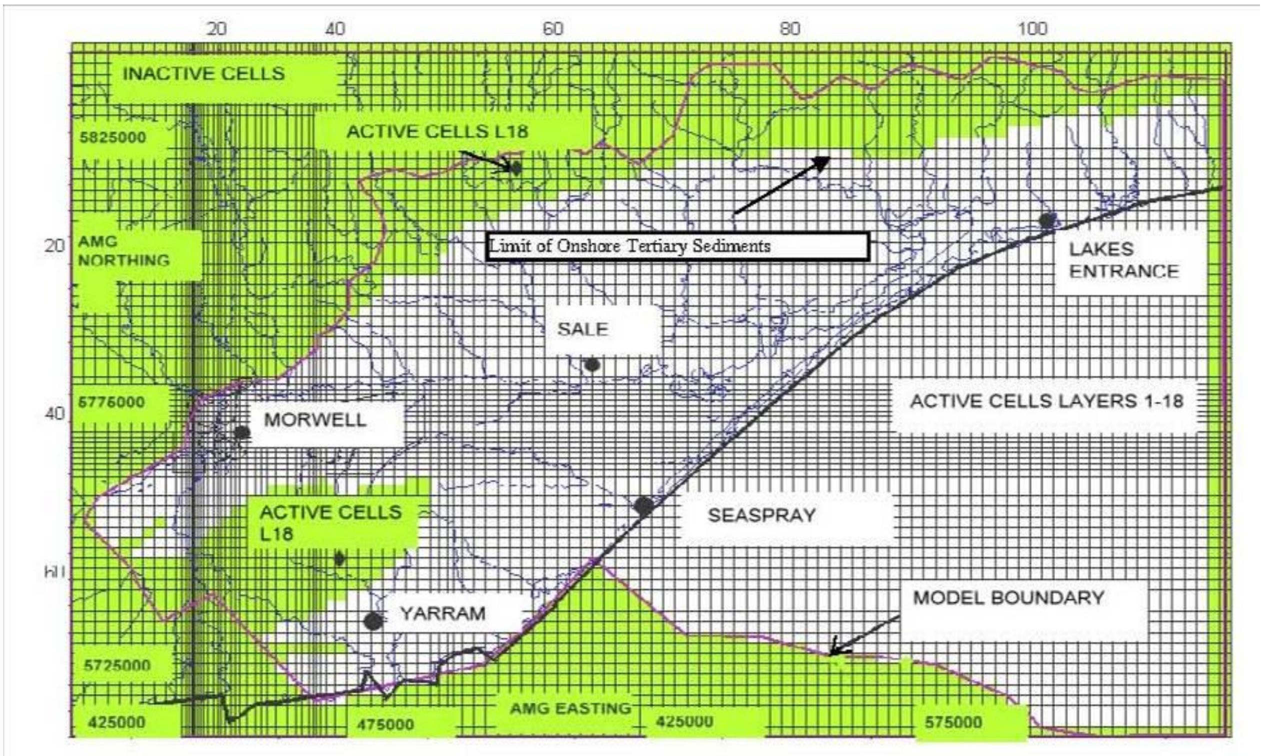


Figure 2 Location of active cells and IRM model domain (sourced from Schaeffer 2008)

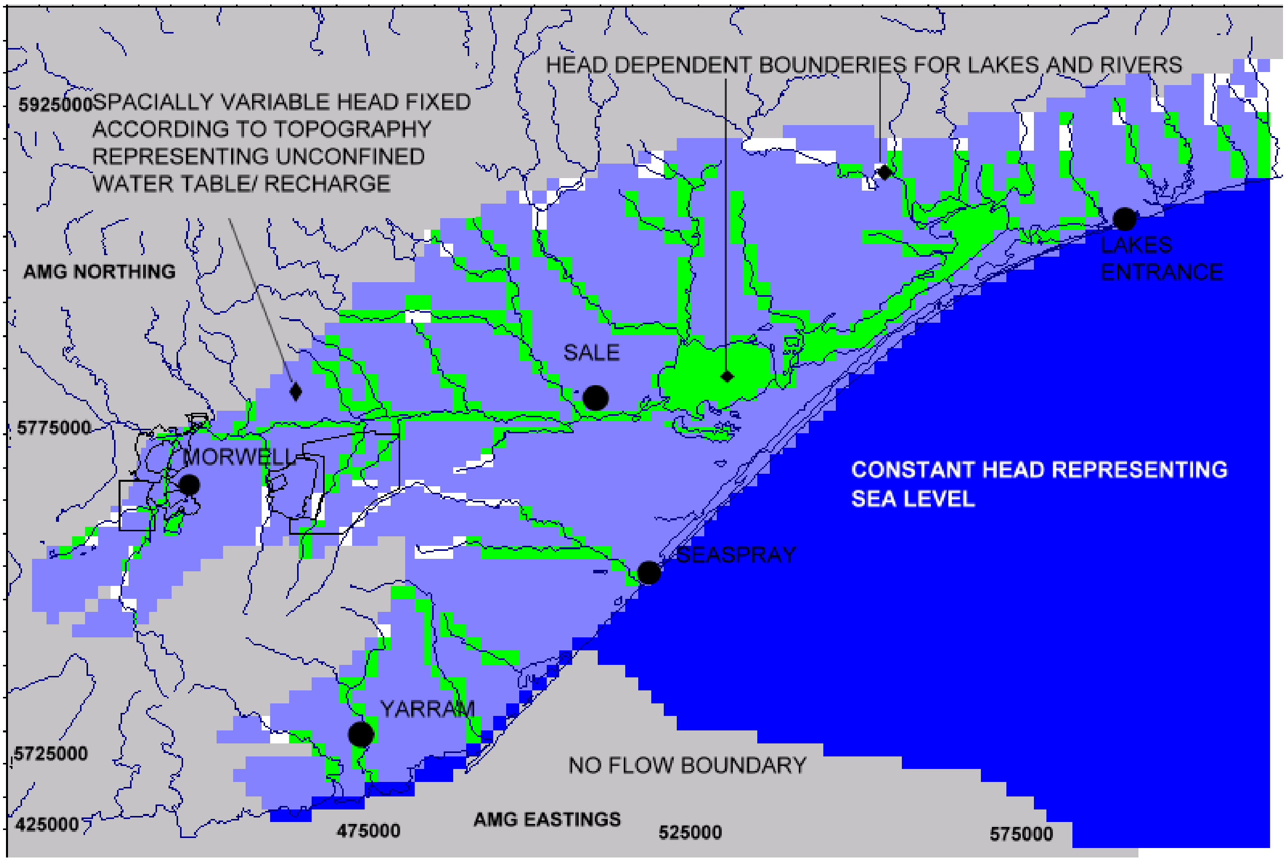


Figure 3 IRM boundary conditions for Layer 1 (source: Schaeffer 2008)

2.6.2.2.3 Review of the ecoMarkets groundwater models

The ecoMarket groundwater models (GHD, 2008; 2010a) were developed to assess potential impacts on depth to the water table and baseflows for a range of land use change scenarios. Two models were developed with identical specifications: one for the West Gippsland Catchment Management Authority (CMA) region and one for the East Gippsland CMA region. Both models extend offshore to the freshwater–seawater interface. The offshore extent of the models was based on structural and stratigraphic mapping. Each model was constructed in MODFLOW (Harbaugh A W 2005) using a 200 m by 200 m grid and consisted seven layers.

In the case of the East Gippsland model, transient head boundaries were used offshore so the effects of offshore oil and gas pumping could explicitly be simulated at the southern model boundary, as shown in Figure 4. Stream cells were used over a large proportion of the high ground area to simulate the streams and rivers, whereas river cells were used to simulate lakes. General head boundary cells were set at an average sea level (0.1 mAHD) across the upper most active layer in all offshore areas. The peer reviewer concluded these boundary conditions were appropriate (PB, 2010a). However, it is noteworthy that the steady-state model for this area did not converge and consequently had a large water balance error. That is, an adequate steady-state calibration was not achieved for the East Gippsland ecoMarkets groundwater model, which has implications for the robustness of the associated transient model.

A review of the East Gippsland model identified that the ability of the model to simulate the actual groundwater flow systems was constrained by a lack of data to define those flow systems over the majority of the modelled area (PB, 2010a). Consequently, the usefulness of this model is effectively limited to a proportion of the lowland areas. The part of the model covering the elevated areas representing the Mesozoic basement outcrop is not reliable and is considered to be of limited use. Even in the lowland areas, the model has significant limitations regarding its primary purpose. The limitations relate to the effects of land use changes, which are likely to be poorly predicted because in many areas the computed heads, hydraulic gradients, trends in heads, and responses to stresses do not match the observed data. As reported by PB (2010a), more effort would be required in the calibration of localised areas for the East Gippsland ecoMarkets groundwater model to be fit for purpose in all areas for which groundwater level data are available.

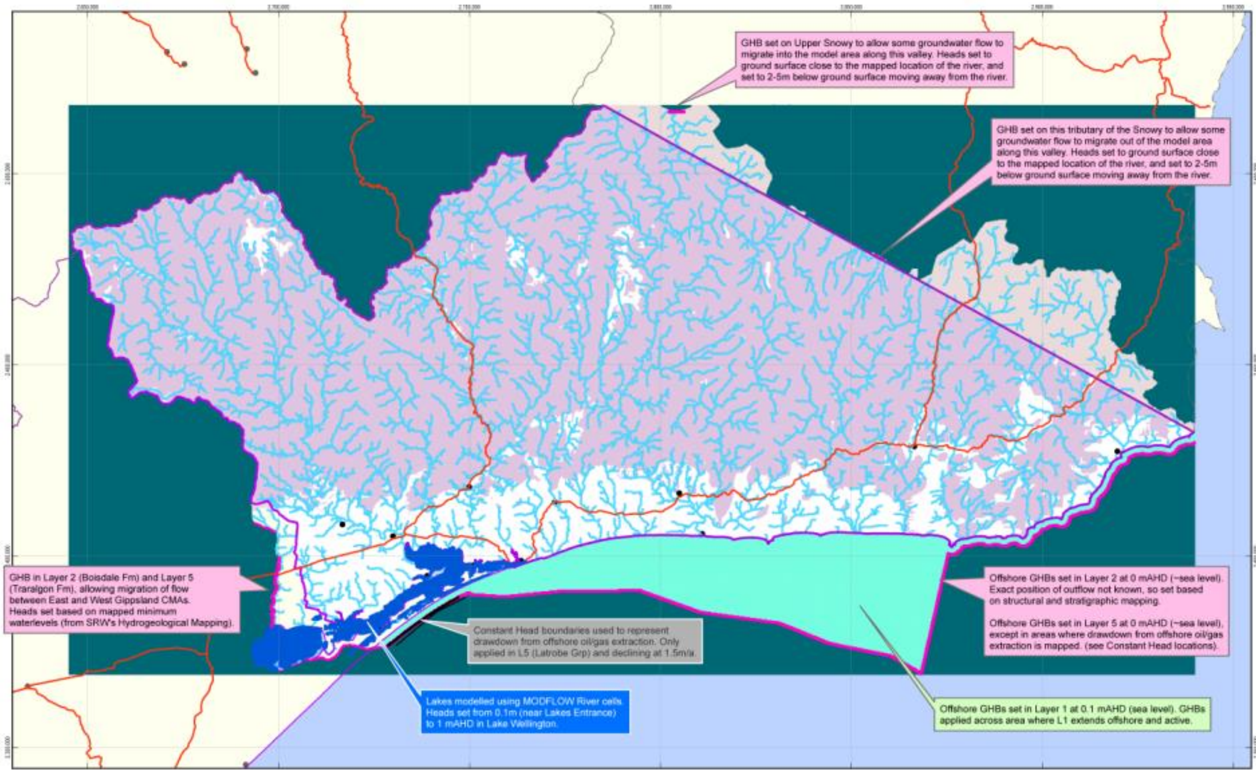


Figure 4 **Domain and boundary conditions for the ecoMarkets East Gippsland groundwater model (source: GHD 2010c)**

In the case of the ecoMarkets West Gippsland groundwater model, the model extends to the onshore topographic divides across which no-flow boundaries are assigned, as shown in **Error! Reference source not found.**. The eastern boundary extends into East Gippsland along the Mitchell River, and the western boundary extends to the offshore freshwater - saltwater interface, along which a no-flow boundary is assigned that forces groundwater to flow up along the interface and discharge far out to sea. The offshore extent of the model is based on structural and stratigraphic mapping.

The shoreline is simulated in Layer 1 only, with a density corrected head of 0.1 mAHD. Stream cells representing third order and higher order streams are used over a large proportion of the high ground area, whereas first and second order streams are represented as drain cells. River boundaries are also used to represent surface water bodies on the lowlands. Time-varying drain cells with high conductance values (10,000 m^2/d) were used to represent the dewatering of coal mines. A reviewer (PB, 2010b) noted that, while this is normal practice, it was not clear why this approach was not successful in reducing adjacent heads to observed levels, given that some heads were identified as being 100 m too high.

Steady-state calibration was based on 1970s pre-development water levels and 1957–2005 average recharge. While a steady-state solution was achieved, no comparative groundwater level contour maps were shown to demonstrate the degree of agreement with the observed groundwater level contour maps. The transient model calibration period was from 1970 to 1985, with monthly stress periods. A warm-up period was run from 1960 to 1969 to provide more sensible initial conditions (than steady-state heads) in a system disturbed by mining and characterised by declining heads. Verification was undertaken from 1986 to 1990. From the statistics and other calibration evidence, PB (2010b) concluded that the model was fit for the purpose as specified for the ecoMarkets study, which focused on the water table aquifer, but could not be used reliably in deeper layers where coal-mining effects are evident in observed datasets.

The peer review of the West Gippsland model by PB (2010b) highlighted that the West Gippsland model was unique among the ecoMarkets models in having to simulate extensive dewatering associated with large coal mining. The review identified that depressurisation caused by coal mining was poorly simulated and consequently the groundwater model could not be recommended for broader water resource management purposes. The review stated that the model might be suitable for this purpose in areas very distant from the mines. In conclusion, the review stated that there is uncertainty over the usefulness of the West Gippsland ecoMarkets groundwater model for the water resource management of deeper aquifers, given the poor simulation of mine depressurisation. This conclusion reinforces the limitation and suitability of this model to evaluate the bioregional assessment and mine depressurisation scenarios.

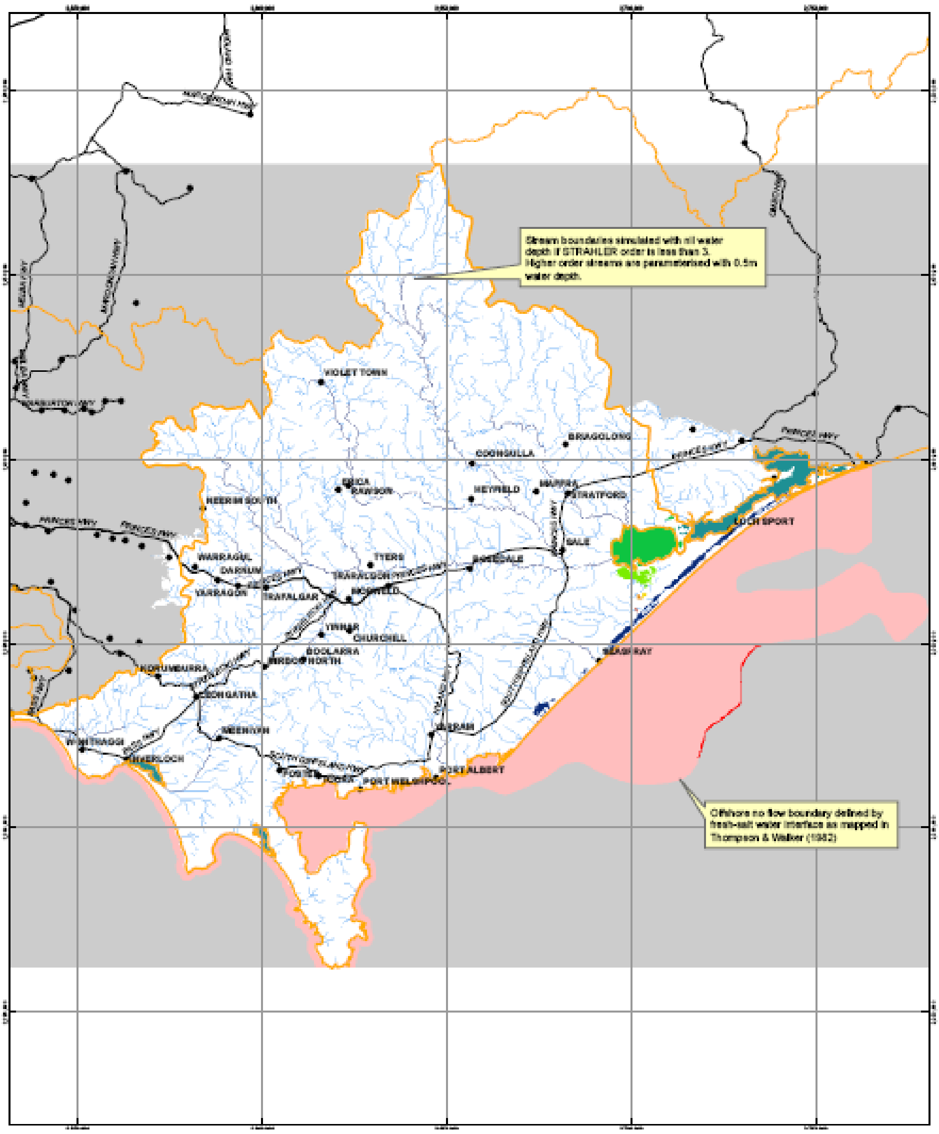


Figure 5 Domain and boundary conditions for the ecoMarkets West Gippsland groundwater models (source: GHD, 2010b)

2.6.2.2.4 Review of the CSIRO groundwater model

The CSIRO Gippsland Basin model was developed in collaboration with DPI Victoria (Geological Survey of Victoria) to assess coal seam gas water management in the Gippsland Basin. The objective of the study was to build and show the capability of the CSIRO in assessing the impact of coal seam gas production on aquifer pressure heads. The study also provided information related to the risk of land subsidence adjacent to coal seam gas production wells. The area selected for the study was a region in the Gippsland Basin with abundant coal mining activity.

The developed model qualitatively predicted the amount of recovered methane and water from single or multiple coal seams which could be separated by either an aquifer or a fine grained clayey-silty material typically considered to be an aquitard. The model coupled geomechanics and fluid flow and as such was capable of predicting possible land subsidence associated with reservoir depletion due to coal seam methane production. The modelling used the FLAC3D axisymmetric finite difference software, which assumes single-phase flow under which water and desorbed gas is modelled as one fluid. That is, the desorbed methane is treated as a chemical species carried with the fluid whereby the transport of methane is controlled by advection and diffusion in water. This model simulates the simultaneous production of two coal seams 50 m and 44 m in thickness separated by another 12 m thick layer of sediments (Freij-Ayoub et al., 2011b). The modelling explores the influence of coal permeability on the quantities of produced methane and water in a well bore.

In addition to the bore modelling using FLAC3D, the CSIRO study developed a numerical groundwater model based on Schaeffer (2008) to assess the impact of economically viable methane gas extractions on the hydraulic heads in aquifers underlying coal seams in the Latrobe Valley (Figure 6). This large-scale study used MODFLOW, which is limited to single phase water production. As such, the impact of methane extraction on the hydraulic heads in the produced or adjacent layers was predicted to be negligible at the basin-wide scale modelled (Freij-Ayoub et al., 2011b). The MODFLOW model considered a domain of 291 km by 186 km with a uniform grid resolution of 1 km by 1 km, and adopted a 10-layered simplified stratigraphic representation of the Gippsland Basin as shown in Figure 7. Of note was that the model assumed that the hydraulic head is hydrostatic. Constant head boundary conditions were assigned based on the assumption that the edge-effect boundary impacts associated with the scenario modelling would be negligible. The domain and boundary conditions are shown in Figure 8. In addition to the large-scale basin-wide model, a smaller scale model was developed specifically for the Latrobe Valley with a domain of 40 km by 20 km with a uniform grid resolution of 100 m by 100 m (Freij-Ayoub et al., 2011b). This model estimated the impact of coal seam gas extractions on hydraulic heads in the Latrobe Valley. In this case, the extraction estimates were predicted using the COMET3 modelling package.

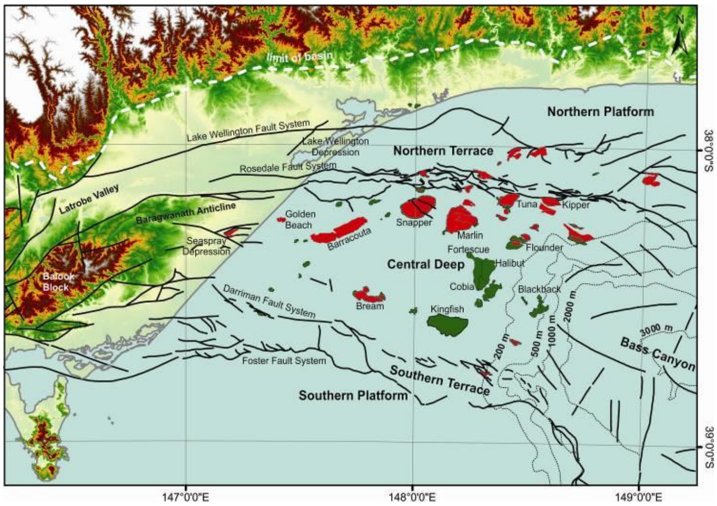


Figure 6 Locality map of the CSIRO large-scale model domain (source: CSIRO, unpublished data)

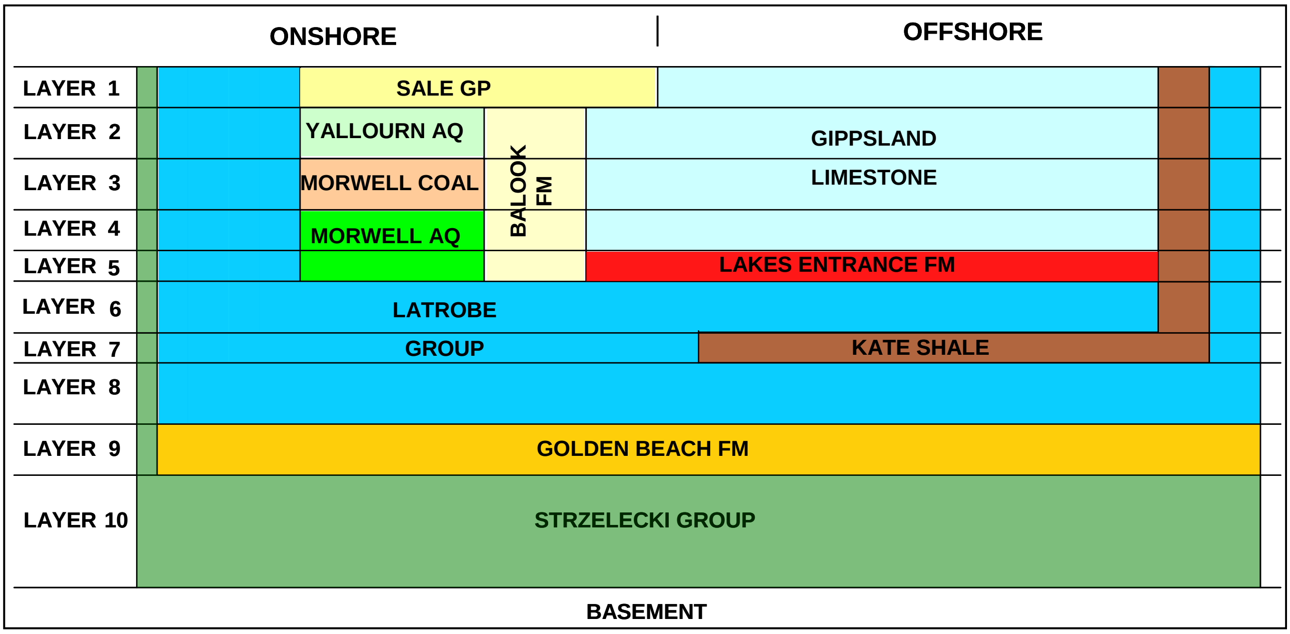


Figure 7 Conceptual model layers adopted in the CSIRO large-scale model (source: CSIRO, unpublished data)

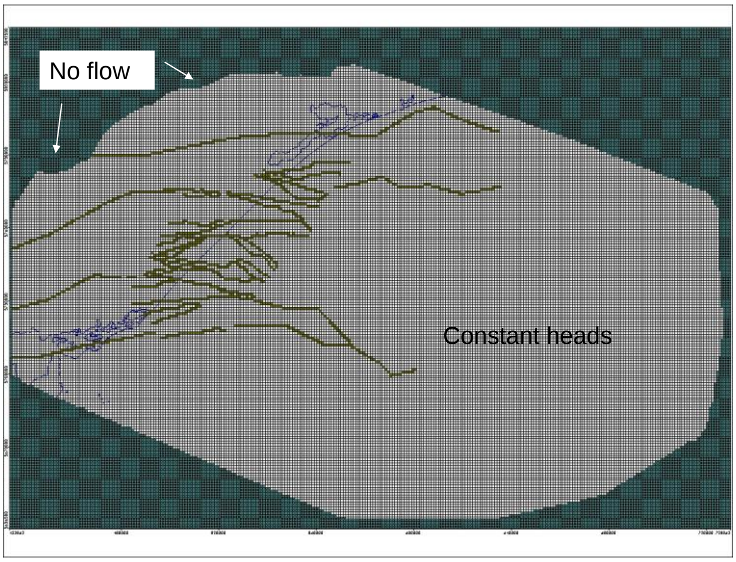


Figure 8 Latrobe Valley finite difference model domain and boundary conditions (source: CSIRO, unpublished data)

2.6.2.2.5 Review of DPI Gippsland Basin groundwater model

The DPI Gippsland Basin model (Beverly et al., 2012) was developed under a collaborative joint project involving the Natural Resources Management and Economics Division (NRME, Vic DPI) and Future Farming Systems Research (FFSR, Vic DPI) with input from GeoScience Victoria (Vic DPI) and the CSIRO Earth Sciences and Resources Engineering Division. The aim of the project was to develop and calibrate an integrated catchment model to assess the likely future impact on the water resource and agricultural sector within the Gippsland Basin due to altered extraction regimes from existing groundwater users, anticipated coal seam gas extractions and proposed energy and earth resource development.

The DPI groundwater model was based on the IRM model developed by Schaeffer (2008) and some offshore elements of the CSIRO basin-wide scale model (Freij-Ayoub et al., 2011b). The model was constructed in MODFLOW and comprised 18 layers of which layers 1–17 were similar to the IRM model extent with the addition of layer 18 representing the basement layer extending to the upland regions of the Gippsland Basin. Key refinements to the original IRM model included (1) finer uniform grid resolution of 200 m, (2) the incorporation of some offshore aquifer stratigraphic information as provided by the CSIRO and Earth Resources and (3) incorporation of a basement layer representing the upland outcropped regions of the Gippsland Basin. The extent of the model is shown in Figure 9.

The objective of this study was to assess the long-term, equilibrium impacts of likely coal seam gas extractions and expanded open cut mining activity on aquifer potentiometric surfaces. As such, the modelling assumed pseudo steady-state conditions based on observed conditions in year 2000.

The DPI model incorporated constant head and no-flow boundary conditions. A no-flow boundary condition was assigned along the onshore northern and western fringes of all layers as these boundaries represented the topographic divides of bedrock outcrops; fixed head boundary conditions were assigned along the coast. A constant head boundary of 0.7 m was assigned to all offshore layer 1 cells representing a density corrected hydrostatic head of the ocean in the offshore area.

Groundwater extractions were based on groundwater licence data provided by Southern Rural Water whereas the offshore extractions were as compiled by Schaeffer (2008). Measured time-varying extractions representing the Latrobe Valley mines were derived from the LVCM model, which also includes the Sale public water supply and the Australian Pulp Mill at Maryvale. In total the DPI groundwater model accounted for 179 groundwater users.

Recharge, potential groundwater evapotranspiration and groundwater extinction depths were derived using the Catchment Analysis Tool (CAT) (Beverly, 2009) which uses a combination of a suite of farming system models linked within a catchment framework with allowance for landscape connectivity and connection to a distributed, multi-layered groundwater model. The farm-scale models account for position in the landscape (topography, soil type, aspect and slope), climate, land use and land management to simulate water balance components (including recharge) and soil/water/plant interactions on a daily time step. The groundwater extinction depth controls the depth below which no groundwater evaporation demand is permitted. The groundwater extinction depths (as with evapotranspiration rates) were spatially varied based on the differing rooting depths of species used in the farming-systems models associated with the overlying land-use as derived using the CAT model.

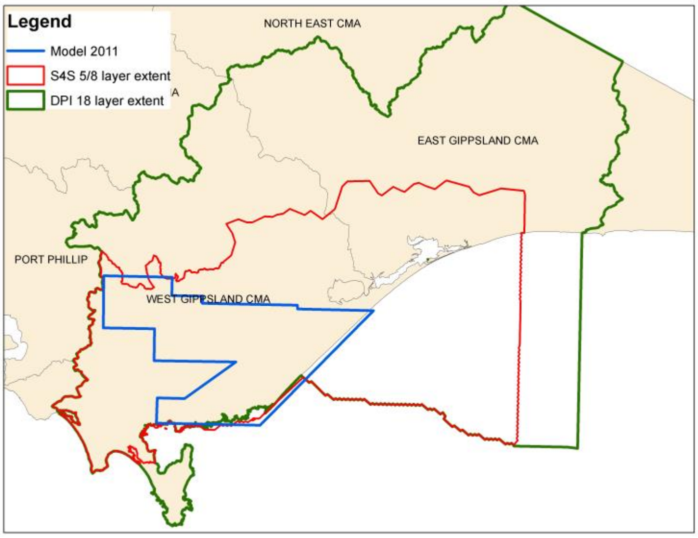


Figure 9 **Extent of the DPI groundwater model. Also shown are previous DPI groundwater model extents (consistent with the IRM model domain) and the CSIRO sub-model region**

2.6.2.2.6 Review of the Victorian Onshore Natural Gas Water Science Studies groundwater model

The Victorian Onshore Natural Gas Water Science Studies (VWSS) was commissioned in 2015 to assist the Victorian Government to determine if the existing moratorium on onshore gas exploration and fracking should be changed based on a review of associated water science impacts. This study required the development of a groundwater model for the Gippsland Basin (both on and offshore) to investigate and understand the potential impacts of future onshore gas developments and to understand the possible impacts of a potential onshore natural gas industry on groundwater and surface waters within the Gippsland region. The groundwater model (Beverly et al., 2015) was constructed in MODFLOW-2005 and adopted a uniform spatial resolution of 400 m with a spatial extent of 6,698,000 ha (66,980 km^2), of which 3,629,000 ha (36,290 km^2) exists onshore and 3,069,000 ha (30,690 km^2) offshore, as shown in Figure 10. The model layer structure and attribution were based on a combination of (1) new stratigraphic mapping and interpretation developed by Geological Survey of Victoria, (2) the Victorian Aquifer Framework (VAF) (SKM, 2011b; GHD, 2012), (3) previous groundwater model data, and (4) existing maps and cross-sections.

The model comprised 30 layers and accounted for coal seams specified as discrete layers and Cretaceous sediments of the Strzelecki formation in discrete sub-layers. Key improvements to the previous DPI Gippsland Basin groundwater model include (1) new interpreted data sets that extend to the catchment boundaries, (2) finer grid resolution, (3) the incorporation of offshore stratigraphic information as developed by the CSIRO and Geological Survey of Victoria, and (4) incorporation of a basement layer representing the rocks underlying the sedimentary basin and extending to the upland regions of the Gippsland region where the basement outcrops.

The transient calibration period adopted annual stress periods from 1970 to 1990, and thereafter monthly stress periods throughout the 1991–2012 calibration/verification periods. These model stress periods were based on adequately capturing historical onshore and offshore extractions, specifically the Latrobe Valley coal mine and offshore oil and gas production wells. To this end, pre-1990 stress periods were assigned as annual within which 12 time-steps were adopted. For the more recent post-1990 calibration/verification period the stress period was based on quarterly time-steps so as to utilise seasonal water level oscillation and extractions data.

The assigned boundary conditions were based on the DPI groundwater model (Beverly et al., 2012) and included no-flow, well, river, drain and constant head boundary conditions. Recharge, potential groundwater evapotranspiration and groundwater extinction depths were derived using the Catchment Analysis Tool (CAT) (Beverly, 2009). Flood induced episodic recharge was simulated in the model by maintaining saturation in the surface soil layer in all regions within mapped flood extents. The duration of inundation was arbitrarily set as 5 days, unless specific information to the contrary was available.

A total of 8175 groundwater extraction bores were incorporated into the model representing groundwater usage bores, mine dewatering bores, stock and domestic bores and offshore production bores. A total of 22,573 river cells were also included in the model representing the main stems of the major rivers. The classification associated with the river spatial data layer was used to vary river incision depth (depth below the ground surface as defined by the digital elevation model) and width attributes. In the absence of recorded stage height information, river classification was used to estimate river stage heights. Drainage channels and man-made drainage features in the Macalister Irrigation District (MID) were included in the model based on available drainage network and groundwater discharge mapping and monitoring.

Seven hypothetical tight and shale gas and coal seam gas (CSG) development scenarios were considered under a dry future climate. Each scenario was designed to estimate the likely water usage of onshore gas development under varying well field designs and configurations.

An external review of the model concluded that the model was conceptualised and calibrated at a design level that meets the requirements of a moderate complexity regional scale groundwater model as defined in the Murray-Darling Basin Commission Groundwater Flow Modelling Guidelines (Middlemis, 2000) and meets the requirements of a Class 2 model confidence level classification as defined in the National Water Commission Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

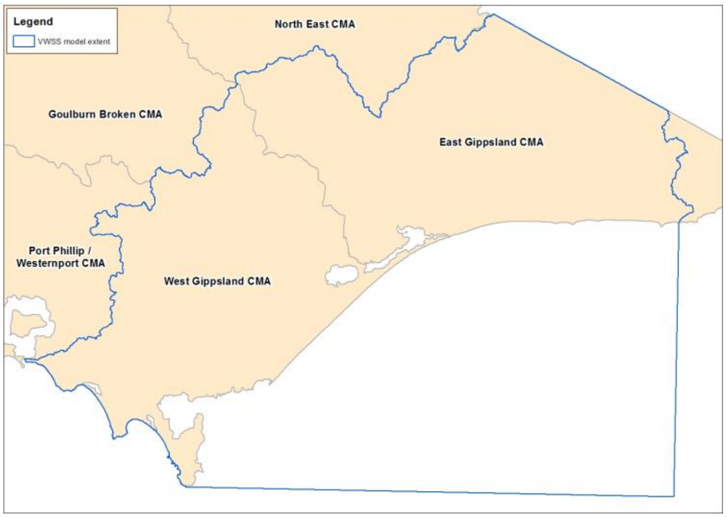


Figure 10 Spatial extent of the Victorian Onshore Natural Gas Water Science Studies groundwater model

2.6.2.2.7 Summary of existing groundwater model attributes

A summary of the relevant model attributes and considerations required for this study is presented in Table 1.

For each of the top five ranked models as reported by SKM (2011a) and including the CSIRO (Freij-Ayoub et al., 2011a), DPI (Beverly et al., 2012) and VWSS (Beverly et al., 2015) models, a score is assigned based on the original ranking procedure adopted in SKM (2011a) using a Multi Criteria Assessment (MCA) approach involving the following steps:

- definition of a set of criteria
- assignment of weightings to the various criteria
- identification of performance objectives for the agreed criteria
- scoring and ranking of the alternatives.

An aggregated performance rating of 1 to 3 was used in which 1 refers to does not meet the set of criteria, 2 satisfies more than 50% of the criteria and 3 satisfies all criteria. It is noteworthy that the SKM (2011a) study compiled results from two independent reviewers.

In general, the MCA analysis identified that, with the exception of the VWSS groundwater model, no prior groundwater management tool adequately satisfies all of the model specifications required for this project. Specifically, the MCA analysis identified that the most recent regional groundwater model (VWSS) had the required spatial extent, vertical resolution and model grid to evaluate the bioregional assessment.

Table 1 Summary of key features of the top five ranked models by SKM (2011a) and the CSIRO model currently under development

Attribute	Yarram sub-regional (SKM 1999)	Gippsland Basin (Nahm 2002)	Sale WSPA (SKM 2008)	Integrated Resource IRM (Schaeffer, 2008)	ecoMarkets (GHD, 2008, 2010a)	CSIRO (Freij-Ayoub et al., 2011a)	DPI (Beverly et al., 2012)	VWSS (Beverly et al., 2015)
Extent focus	Onshore	offshore	onshore	onshore, offshore	Onshore	offshore	onshore	onshore, offshore
Inclusion of offshore extractions	1	2	1	3	1	3		3
Representation of within-Basin structural features	2	2	2	2	2	2		2
Number of layers	4	7	4	18	7	10	18	30
Grid resolution	500–2,000 m	?	1 km	1 km	200 m	1 km	200 m	400 m
Representation of major aquifers and aquitards	1	2	1	3	2	3	3	3
Representation of both onshore and offshore hydrogeology	2	2	0	3	2	3	3	3
Representation of appropriate boundary conditions	1	2	1	3	3	3	3	3
Accurate representation of groundwater/surface water interface	1	2	2	2	1	2	3	3
Ability to represent abstraction and injection wells	2	2	2	3	3	3	3	3
Ability to determine extraction impacts on environment/users	2	2	2	3	2	3	3	3
Ability to identify shallow water tables	2	2	2	3	2	3	3	3
Ability to simulate steady-state conditions	3	?	3	3	2	3	3	3

2.6.2.3 Model development

Summary

To assess the impact of coal resource development on groundwater receptors, water table elevations and surface water groundwater exchange fluxes within the Gippsland Basin, a distributed, multi-layered groundwater model was developed in MODFLOW-2005. The groundwater model comprises 30 layers representing the key aquifers, aquitards and coal seams. Recharge and potential groundwater evapotranspiration are derived using a catchment modelling framework that accounts for land management practices at variable land management scales. The regional groundwater model incorporates comprehensive usage data to account for groundwater extractions, stock and domestic, mine dewatering and offshore production demands.

2.6.2.3.1 Objectives

The regional distributed groundwater model was developed to help quantify the potential groundwater and surface water impacts of coal resource development pathways in the Gippsland region. The model will be used to quantify impacts arising from potential developments (both individually and cumulatively) including:

- the drawdown in hydraulic heads
- the reduction in baseflow to rivers that drain the basin
- the reduction in water availability to groundwater-dependent ecosystems.

The minimum specifications required to meet the project objectives were:

- uniform finite difference grid of no more than 400 m cell size
- model domain represents the entire Victorian Gippsland region and extends offshore to adequately represent oil and gas extractions
- 30 modelled layers representing the major geological units and consistent with existing documented hydrostratigraphic units
- 822 groundwater monitoring observation bores used for calibration
- 8,175 groundwater pumping bores representing licensed pumping, domestic and stock usage and offshore oil and gas platforms
- recharge estimates (steady-state and transient) generated using the Catchment Analysis Tool (CAT) (Beverly, 2009) farming system models and provided by DEDJTR
- allowance for episodic flood recharge events
- groundwater evapotranspiration extinction depth to be based on land use
- groundwater evapotranspiration rate to account for unsaturated vegetation evapotranspiration rates such that the summed saturated and unsaturated

evapotranspiration does not exceed potential evapotranspiration as calculated from meteorological data

- a normalised (scaled) root mean squared error (RMS) of less than 5% for the steady-state model based on matching hydraulic head observation data
- a normalised (scaled) RMS of less than 10% for the transient model based on matching hydraulic head observation data at selected and agreed sites
- existing mapped depth to water table and groundwater baseflow estimates to be considered
- a transient split calibration/validation period of 10 and 13 years respectively (1990–99 and 2000–12)
- a sensitivity analysis to assess the variability of modelled outputs to variations in key model input parameters
- catchment-scale model water balance error of less than 2%
- all significant catchment water balance features to be considered and reported
- the source and a statement of quality of all input data sets to be reported
- accuracy in drawdown outputs within 5 to 10 m
- an annual time step for the simulation period 1970–1989 and thereafter monthly time steps for the simulation period 1990–2012 and beyond, which was considered to be sufficiently small to determine adverse impacts during periods of low surface water flow but also mindful of the impact on model run time.

2.6.2.3.2 Hydrogeological conceptual model

A schematic conceptual understanding of the water balance and hydrogeology within the Gippsland region is presented in Figure 11. The important water balance features considered within the model include:

- groundwater recharge
- groundwater inflow and outflow
- groundwater abstraction
- groundwater evapotranspiration
- groundwater – surface water interaction.

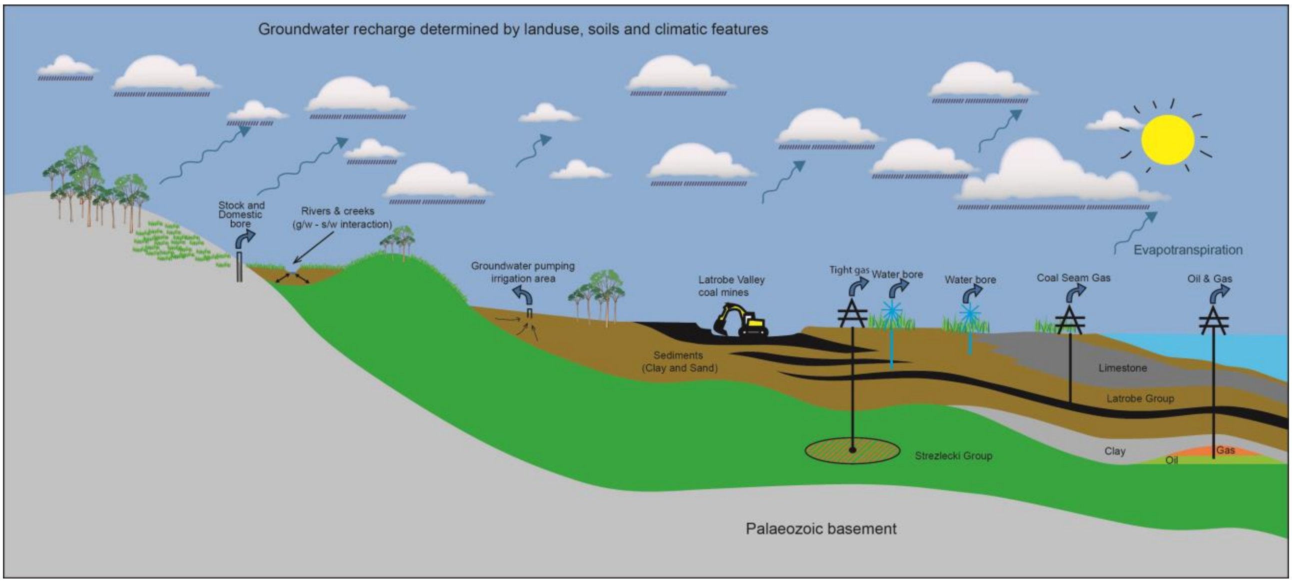


Figure 11 Stylised conceptualisation of the dominant water balance components within the Gippsland region

The regional groundwater flow conceptualisation considers the Tertiary aquifers in the Gippsland region as behaving as three distinct flow systems underlain by the regional basement aquifer of the Strzelecki Group. The most significant of the Tertiary aquifers are the Moe Sub-basin, Latrobe Valley, Seaspray Depression (in which the catchments of the Thomson, Latrobe and Mitchell rivers occur) and Southern Terrace (which includes the catchment of the Tarra River).

Flow in the Northern Terrace and Seaspray Depression aquifers is dominantly west to east, with limited lateral interconnectivity due to both faulting and the Baragwanath Anticline (see Figure 12). Flow in the southern terrace is topographically driven off the southern slopes of the Strzelecki ranges.

Hatton et al (2004) noted the widespread declines in aquifer pressures in the Seaspray Depression 'are clearly associated to some large but geographically variable degree with offshore oil and gas production'. These declines and the cone of depression associated with dewatering at the Loy Yang and Hazelwood mines are distinctly disconnected responses. The other basins are the Tarwin Basin (included in the model domain) which is effectively a disconnected basin flowing south, and the Westernport Basin flowing westerly towards Westernport Bay (and is not included in the model domain).

The conceptual model considers flows in the exposed meta-sediments in the high-relief areas of the Strzelecki and Eastern Highlands are primarily local flow systems discharging to nearby streams with some recharge to the basement rocks. Regional scale flows occur in deeper tertiary units where recharge primarily occurs on the margins of basins where the units sub-crop or outcrop, dominated by rainfall (GHD, 2010d).

Coal, silt and clay layers are effective aquitards over the region. However, the complex depositional history results in regional scale connections between aquifers within coal seams. The Balook Formation in particular provides a significant connection between the Morwell and Traralgon Formation aquifers and the Boisdale Aquifer.

The aquifers of the Latrobe Formation contain good quality water for many kilometres offshore indicating this groundwater is formation water associated with deposition and a result of long-term flow from onshore. However, near the seaward margin much higher salinities are encountered which are considered to pre-date the onset of oil and gas production and represent formation water.

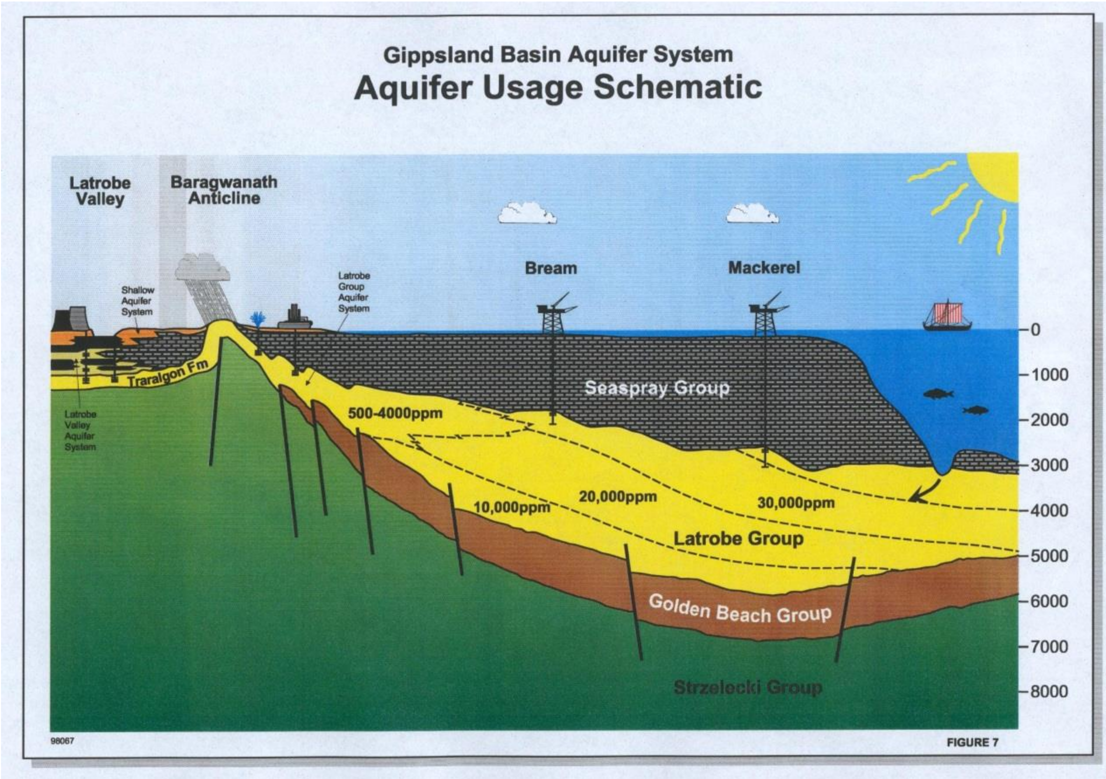


Figure 12 Schematic flow conceptualisation of the Seaspray Depression showing the Baragwanath anticline and typical water quality variation offshore (source: DNRE unpublished data)

2.6.2.3.3 Design and implementation

The model consists of 30 layers and includes coal seams similar to those represented in the IRM model in addition to a basement layer that extends to the upland regions of the Gippsland region. Key refinements to the previous DEPI Gippsland Basin groundwater model include: (1) new interpreted data layers that extend to the catchment boundaries; (2) finer grid resolution; (3) the incorporation of offshore aquifer stratigraphic information as developed by the CSIRO and Geological Survey of Victoria; and (4) the incorporation of a basement layer representing the upland outcropped regions of the Gippsland region.

Table 2 summarises the grouping of coal and interseams into modelled layers, and also provides the associated Victorian Aquifer Framework (VAF) (SKM, 2011; GHD, 2012a) code and relevant references defining the extent and thicknesses of each modelled layer. Importantly, all dominant coal seams were specified as individual layers. Model layers 23 to 29 represent the Strzelecki Group. Rather than allocating this as a single layer, it was necessary to split this geological unit into six model layers to accommodate the likely scenarios which require depressurisation within parts of this unit.

Table 2 Groundwater model layers and associated Victorian Aquifer Framework (VAF) code, coal name and general description of stratigraphic groupings

Model layer	Inputs and VAF code	Name	Coal name	Geology	Description / Comment	References
1	Bathymetry	Marine Water		Marine water thickness	Marine water thickness	Whiteway (2009)
2	VAF 101	QA		Quaternary	Quaternary	GHD (2012) SKM (2009)
3	VAF 102; -10m elevation contour	UTQA		Haunted Hill Formation	Haunted Hill Formation	GHD (2012) SKM (2009)
4	VAF 103	UTQD		Nuntin clay	Nuntin clay	GHD (2012) SKM (2009)
5	VAF 105	UTAF		Boisdale Formation	Boisdale Formation	GHD (2012) SKM (2009)
6	VAF 106	UTD		Jemmy's Point Formation and upper Hazelwood Formation	Jemmy's Point Formation and upper Hazelwood Formation	GHD (2012) SKM (2009)
7	VAF 106 Yallourn Coal (isopach)	Y COAL	Yallourn Coal Seam	Yallourn coal seams; 1,1a, 1b and 2	Y, Y1a, Y1b, Y2, Y1; y_all	GHD (2012) SKM (2009) GHD (2011)
8	VAF 106 Yallourn Coal Interseam	Y Interseam	Yallourn Aquifer & interseam	y_all floor & M1a_all top	Hazelwood Formation; y_all floor & M1a_all top	GHD (2012) SKM (2009) GHD (2011)
9	UMTA 107 UMTD 108	UMT A&D	Lower M2 interseam,	Balook Formation Tambo River, Wuk Marl, Gippsland Limestone, Morwell Coals	Balook Formation Tambo River, Wuk Marl, Gippsland Limestone	GHD (2012) SKM (2009)
10	UMTA 107 Morwell 1A coal (isopach)	M1A COAL	M1A coal	Yarragon Formation, M10, M1a, M1b2, ML, M12; M1a_all	Yarragon Formation, M10, M1a, M1b2, ML, M12; M1a_all	GHD (2012) SKM (2009) GHD (2011)

Model layer	Inputs and VAF code	Name	Coal name	Geology	Description / Comment	References
11	UMTA 107 Morwell 1A Interseam	M1A Interseam	Morwell 1A interseam/aquifer	M1a_all_floor & M1b_top	M1a_all_floor and M1b_top	GHD (2012) SKM (2009) GHD (2011)
12	UMTA 107 Morwell 1B coal (isopach)	M1B COAL	Morwell 1B coal	M1b, M1b1, M1b2, ML, M12	M1b, M1b1, M1b2, ML, M12	GHD (2012) SKM (2009) GHD (2011)
13	UMTA 107 Morwell 1B Interseam	M1B Interseam	Morwell 1B interseam	Floor M1b_all & M2_all top	Floor M1b_all & M2_all top	GHD (2012) SKM (2009) GHD (2011)
14	UMTA 107 Morwell 2 coal (isopach)	M2 COAL	Morwell 2	M2, M2A, M2B coal; M2_all	M2, M2A, M2B coal; M2_all	GHD (2012) SKM (2009) GHD (2011)
15	LEF Top; LEF Terminal Seal; LEF well picks	LEF		Lake Entrance Formation	Lakes Entrance Formation	McLean & Blackburn. (2013); (Blevin et al, 2013); Goldie Divko pers. comm. (2014)
16	LMTA 109 Morwell 2 interseam,	LMTA		M2c aquifer/Seaspray sands	M2c aquifer/Seaspray Sands	GHD (2012) SKM (2009)
17	LTB 112	LTB		Thorpdale Volcanics	Thorpdale Volcanics	GHD (2012) SKM (2009)
18	LTA 111 Top Latrobe Petroleum wells	LTA		Upper Latrobe Group	Upper Latrobe Group	GHD (2012) SKM (2009) McLean & Blackburn (2013)

Model layer	Inputs and VAF code	Name	Coal name	Geology	Description / Comment	References
19	LTA 111 T0 & T1 Coal Petroleum wells	T1 COAL	T1 coal	TP, T1, TRU, TRM, TRL	TP, T1, TRU, TRM, TRL	GHD (2012) SKM (2009) GHD (2011)
20	LTA 111 T1-T2 interseam Petroleum wells	T1 Interseam	T1 interseam	Floor T1_all and Top T2_all	Floor T1_all and Top T2_all	GHD (2012) SKM (2009) GHD (2011)
21	LTA 111 T2 coal Petroleum wells	T2 COAL	T2 coal	T2 coal seams		GHD (2012) SKM (2009) GHD (2011) Osbourne et al. (2014)
22	LTA 111 T2 interseam Petroleum wells	T2 Interseam	T2 interseam	Lower Latrobe Group; T2_all floor	Lower Latrobe Group; T2_all floor	GHD (2012) SKM (2009) GHD (2011) Osbourne et al. (2014)
23	BSE 114	STRZ		Strzelecki 500 m; >0–500 m	Strzelecki top 500 m	GHD (2012) SKM (2009) McLean and Blackburn (2013)
24	BSE 114	STRZ1		Strzelecki 500 m; >500–1000 m	Strzelecki 500–1000 m	GHD (2012) SKM (2009) McLean and Blackburn (2013)
25	BSE 114	STRZ2		Strzelecki 1 km; >1000–2000 m	Strzelecki 1–2 km	GHD (2012) SKM (2009) McLean and Blackburn (2013)

Model layer	Inputs and VAF code	Name	Coal name	Geology	Description / Comment	References
26	BSE 114	STRZ3		Strzelecki 2 km; >2000–3000 m	Strzelecki 2–3 km	GHD (2012) SKM (2009) McLean and Blackburn (2013)
27	BSE 114	STRZ4		Strzelecki 2 km; >3000–4000 m	Strzelecki 3–4 km	GHD (2012) SKM (2009) McLean and Blackburn (2013)
28	BSE 114	STRZ5		Strzelecki 3 km; >3000–7000 m	Strzelecki 4–6 km	GHD (2012) SKM (2009) McLean and Blackburn (2013)
29	BSE 114	STRZ6		Strzelecki; >7000 m	Strzelecki >6 km	GHD (2012) SKM (2009) McLean and Blackburn (2013)
30	BSE 114	PALEO		Palaeozoic basement 200 m thick	Palaeozoic basement	GHD (2012) SKM (2009) McLean and Blackburn (2013) Stuart-Smith et al. (2010) Constantine (2009)

2.6.2.3.4 *Modelled hydrogeological units*

The modelled hydrogeological units are summarised in Table 3. Included in this table are the associated Victorian Aquifer Framework (VAF) code, the hydrogeological unit, the method used to define the extent and the thickness of each modelled layer. The spatial extents of each modelled hydrogeological unit are shown in Figure 13 to Figure 42.

Table 3 Modelled hydrogeological units and associated Victorian Aquifer Framework (VAF) code, derivation method and thickness

Model layer	Inputs and VAF code	Hydrogeological Unit	Geology	Description of generation procedure	Thickness
1	Bathymetry	HGU 1 (Marine Water)	Represents marine waters throughout the offshore portion of the modelled area	The unit top is mean sea level and the unit bottom is the sea floor. Marine waters extend beyond the modelled area. Marine Water is clipped to the model extent in the south and east and the coastline in the northwest. Bathymetry is from Whiteway (2009).	The thickness of Marine Water ranges from 2 m at the coastline to 455 m in the southeast corner.
2	VAF 101	HGU 2 (QA)	Represents the Quaternary Alluvium and includes Fluvial, lacustrine, alluvial and colluvial sediments. Quaternary Alluvium overlies the Haunted Hill Formation in the valleys and the Strzelecki Group and Palaeozoic Basement in the highlands	The QA HGU is based on the aquifer QA from (GHD, 2012; SKM 2009). QA extends to the Gippsland coast.	The thickness of Quaternary Alluvium ranges from 2 m to 105 m in small isolated pockets.
3	VAF 102; -10m elevation contour	HGU 3 (UTQA)	Represents the Upper Tertiary Quaternary Alluvium and includes the Haunted Hill Formation.	The UTQA HGU is based on the aquifer UTQA from (GHD, 2012; SKM, 2009). UTQA was extended offshore by re-gridding using bathymetry and a 1 km buffer zone. UTQA was modified to account for the offshore pinching out of the unit Haunted Hill Formation. The unit extends to the 10m bathymetric contour.	The thickness of UTQA ranges from 2 m to 175 m near Lake Wellington.
4	VAF 103	HGU 4 (UTQD)	Represents the Upper Tertiary Quaternary Aquitard which includes the Haunted Hills Gravel, Eagle Point Sand and Boisdale Formation (Nuntin Clay Member).	The UTQD HGU is based on the aquitard UTQD from (GHD,2012; SKM, 2009). UTQD was extended offshore by re-gridding with bathymetry and using a 15 km buffer zone. UTQD was modified to account for the offshore pinching out of the unit. The surface extends to the 40m bathymetric contour.	The thickness of UTQD ranges from 2 m to 157 m west of Sale.

Model layer	Inputs and VAF code	Hydrogeological Unit	Geology	Description of generation procedure	Thickness
5	VAF 105	HGU 5 (UTAF)	Represents the Upper Tertiary Aquifer which includes the Boisdale (Wurruk Sand Member).	The UTAF HGU is based on the aquifer UTAF from (GHD,2012; SKM,2009). UTAF was extended offshore by re-gridding with Bathymetry and using a 20 km buffer zone. UTAF was modified to account for the offshore pinching out of the Wurruk Sand Member. The surface extends to the 45m bathymetric contour.	The thickness of UTAF ranges from 2 m to 141 m beneath Lake Victoria.
6	VAF 106	HGU 6 (UTD)	Represents the Upper Tertiary Aquitard and includes the Hazelwood Formation, Yallourn Formation and Jemmys Point Formation.	The UTD HGU is based on the aquitard UTD from (GHD,2012; SKM, 2009). UTD was extended offshore by re-gridding with Bathymetry and using a 40 km buffer zone. UTD was modified to account for the offshore pinching out of the Jemmys Point Formation. The surface extends to the 55 m bathymetric contour.	The thickness of UTD ranges from 2 m to 200 m southwest of Rosedale.
7	VAF 106 Yallourn Coal (isopach)	HGU 7 (Y COAL)	Represents the Yallourn Coal seams (Y Coal) and includes the Yallourn Y1A, Y1B and Y2 coal seams.	Coal seam isopachs and extents were determined from the Latrobe Valley coal model Yallourn Coal seams (Jansen and Maher, 2003; GHD, 2011b; Osbourne et al., 2014). These isopachs have been incorporated into UTD (6).	The thickness of Y Coal ranges from 2m to 228m north of Rosedale.
8	VAF 106 Yallourn Coal Interseam	HGU 8 (Y Interseam)	Represents the Yallourn interseam. Y Interseam represents the sediments below the Yallourn Coal floor and above the Morwell Coal roof.	This interseam was incorporated into UTD (6).	The thickness of Y Interseam ranges from 2m to 160m beneath Hazelwood.
9	UMTA 107 UMTD 108	HGU 9 (UMT A&D)	Represents the Upper Mid-Tertiary Aquifer and Aquitard. This includes the Morwell, Balook and Tambo River Formations and the Gippsland Limestone.	The UMT HGU is based on the aquifer UMTA and aquitard UMTD from (GHD, 2012; SKM, 2009). To merge UMTA and UMTD the boundary was re-gridded to smooth conflicts. This occurred through the area of overlap between UMTA and UMTD. UMT was extended offshore by re-gridding with bathymetry and using a 40km buffer zone. The buffer was designed to account for the offshore pinching out of the Jemmys Point Formation. UMT was modified to account for the significant volume of the Gippsland Limestone. Proximal to corner inlet onshore, the UMT was re-gridded to align with petroleum wells and remove conflicts with Strzelecki. The re-gridding occurred over an area approximately 20kmx20km. The UMT extends beyond the study area where it has been clipped.	The thickness of UMT ranges from 2m to 428m offshore central deep.

Model layer	Inputs and VAF code	Hydrogeological Unit	Geology	Description of generation procedure	Thickness
10	UMTA 107 Morwell 1A coal (isopach)	HGU 10 (M1A COAL)	Represents the Morwell 1A Coal Seam (M1A).	Coal seam isopachs and extents were determined from the Latrobe Valley coal model M1A seams (Jansen and Maher, 2003; GHD 2011b; Osbourne et al., 2014). M1A was incorporated into UMT (9).	The M1A Coal thickness ranges from 2m to 228m east of Traralgon.
11	UMTA 107 Morwell 1A Interseam	HGU 11 (M1A Interseam)	Represents the interseam between the Morwell 1A Coal floor and the Morwell 1B Coal roof.	The M1A interseam was incorporated into UMT (9).	The thickness of the M1A Interseam ranges from 2m to 252m south of Rosedale.
12	UMTA 107 Morwell 1B coal (isopach)	HGU 12 (M1B COAL)	Represents the Morwell 1B (M1B) coal seams.	Coal seam isopachs and extents were determined from the Latrobe Valley coal model M1B seams (Jansen and Maher 2003; GHD, 2011b; Osbourne et al., 2014). M1B was incorporated into UMT 9.	The M1B Coal thickness ranges from 2 m to 252 m proximal to Morwell.
13	UMTA 107 Morwell 1B Interseam	HGU 13 (M1B Interseam)	Represents the Morwell 1B interseam between the Morwell 1B coal floor and Morwell 2 coal roof.	M1a Interseam was incorporated within UMT 9.	The thickness of the M1B Interseam ranges from 2m to 252m proximal to Rosedale.
14	UMTA 107 Morwell 2 coal (isopach)	HGU 14 (M2 COAL)	Represents the Morwell 2 Coal Seam (M2).	Coal seam isopachs and extents were determined from M2 coals, (Jansen and Maher, 2003; GHD 2011b; Osbourne et al., 2014). M2 was incorporated into UMT (9).	The M2 Coal thickness ranges from 2m to 239m east of Rosedale.
15	LEF Top; LEF Terminal Seal; LEF well picks	HGU 15 (LEF)	Represents the Lakes Entrance Formation. The Lakes Entrance Formation thickness ranges from 2m to 605m offshore in the central deep.	The LEF HGU is based on the top Lakes Entrance Formation from McLean & Blackburn (2013). LEF was extended onshore by re-gridding with petroleum well control. The surface extends to the terminal effective seal proposed by Blevin et al. (2013) although it is acknowledged that sealing characteristics will extend onshore beyond this line.	The Lakes Entrance Formation thickness ranges from 2m to 605m offshore in the central deep.
16	LMTA 109 Morwell 2 interseam,	HGU 16 (LMTA)	Represents the Lower Mid Tertiary Aquifer and contains the Morwell 2C aquifer and Seaspray Sands.	The LMTA HGU is based on the aquifer LMTA from (GHD, 2012; SKM, 2009). LMTA isopachs and extent were determined and were then incorporated above HGU 18. No offshore extension was modelled for this aquifer.	The LMTA thickness ranges from 2m to 123m proximal to Longford.
17	LTB 112	HGU 17 (LTB)	Represents the Lower Tertiary Basalts.	The LTB HGU is based on the aquifer LTB from (GHD, 2012; SKM, 2009). LTB was not extended offshore.	The Lower Tertiary Basalts range in thickness ranges from 2m to 163m proximal to Yarragon.

Model layer	Inputs and VAF code	Hydrogeological Unit	Geology	Description of generation procedure	Thickness
18	LTA 111 Top Latrobe Petroleum wells	HGU 18 (LTA)	Represents the Lower Tertiary Aquifer and contains the Traralgon coals, Cobia Subgroup, Halibut Subgroup, Golden Beach Subgroup, and Emperor Subgroup.	The LTA HGU is based on the aquifer LTA from (GHD, 2012; SKM, 2009). LTA was extended offshore by re-gridding with top Latrobe (McLean & Blackman, 2013). Well intersections used to better constrain top LTA were applicable. This has particularly the case onshore proximal to 90 mile beach. The unit extends to the model extent in the east. In the southeast the LTA extent is based upon the interpretations from Blevin et al. (2013).	The Latrobe Aquifer ranges in thickness from 2m to 1192m offshore in the central deep.
19	LTA 111 T0 & T1 Coal Petroleum wells	HGU 19 (T1 COAL)	Represents the Traralgon T0 and T1 coal seams and T0 inter-burden (T1 Coal).	Coal isopachs and extents were determined for TP, TRU, TRM and TRL from the Latrobe Valley Coal Model (Jansen and Maher, 2003; GHD, 2011b; Osbourne et al., 2014). Additional Coal isopachs were determined for T0 and T1 from Holdgate et al. (2000). Coal model isopachs were aggregated and extended offshore by merging with T0/T1 isopachs. Depth control was derived the coal model and petroleum wells where available. T1 Coal was incorporated into LTA 18.	The T1 Coal ranges in thickness from 2 m to 133 m near Yarram and Longford.
20	LTA 111 T1-T2 interseam Petroleum wells	HGU 20 (T1 Interseam)	Represents the Traralgon T1 aquifer and includes the T1 interseam.	T1 Interseam isopachs and extents were determined by subtracting T2 Coal roof from T1 Coal floor. Petroleum wells were used for depth control where available. T1 Interseam was incorporated into LTA 18.	The T1 Interseam ranges in thickness from 2 m to 562 m offshore from Lake Wellington.
21	LTA 111 T2 coal Petroleum wells	HGU 21 (T2 COAL)	Represents the Traralgon T2 coal seams and minor interseams (T2 Coal).	Coal isopachs and extents were determined for T2A, T2B from the Latrobe Valley Coal Model (Jansen and Maher 2003; GHD 2011b; Osbourne et al., 2014). Additional Coal isopachs for the T2 coals were taken from Holdgate et al, (2000). Coal model isopachs were aggregated and extended offshore by merging with T2 isopachs. Depth control was derived from the coal model and petroleum wells where available. T2 Coal was incorporated into LTA 18.	The T2 coals range in thickness from 2 m to 448 m with the thicker coals tracing the Baragwaneth Anticline and thinner coals north of the Rosedale Fault.
22	LTA 111 T2 interseam Petroleum wells	HGU 22 (T2 Interseam)	Represents the Traralgon T2 inter-burden (aquifer) below the T2 coal seams.	T2 Interseam isopachs and extents were determined by subtracting LTA top from T2 Coal floor. Petroleum wells were used for depth control where available. T2 Interseam was incorporated into LTA 18.	The T2 Interseam ranges in thickness from 2 m to 2645 m offshore where top Strzelecki Group is deeper.

Model layer	Inputs and VAF code	Hydrogeological Unit	Geology	Description of generation procedure	Thickness
23	BSE 114	HGU 23 (STRZ)	Represents the upper 500 m of the Strzelecki Group and includes the Wombat gas fields near Seaspray and the historical Black Coal mines at Wonthaggi.	Areas where the Palaeozoic Basement outcrops were clipped from BSE, GHD (2012), to produce the Strzelecki HGU onshore. This surface was then blended with the offshore top Strzelecki (McLean and Blackburn, 2013) using a 10km feathering distance. The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strzelecki ranges in thickness from 2 m to 624 m.
24	BSE 114	HGU 24 (STRZ1)	Represents from 500 m to 1000 m depth within the Strzelecki Group.	The Strzelecki Group was arbitrarily subdivided by subtracting a 500 m thick slab from Strzelecki (23). The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strzelecki1 ranges in thickness from 2 m to 545 m.
25	BSE 114	HGU 25 (STRZ2)	Represents from 1000 m to 2000 m depth within the Strzelecki Group.	The Strzelecki Group was arbitrarily subdivided by subtracting a 1000m thick slab from Strzelecki1 (23). The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strzelecki2 ranges in thickness from 2 m to 1000 m.
26	BSE 114	HGU 26 (STRZ3)	Represents from 2000 m to 3000 m depth within the Strzelecki Group.	The Strzelecki Group was arbitrarily subdivided by subtracting a 1000m thick slab from Strzelecki2 (25). The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strzelecki3 ranges in thickness from 2 m to 1000 m.
27	BSE 114	HGU 27 (STRZ4)	Represents from 3000 m to 4000 m depth within the Strzelecki Group.	The Strzelecki Group was arbitrarily subdivided by subtracting a 500-m thick slab from Strzelecki3 (26). The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strez4 ranges in thickness from 2 m to 1000 m.
28	BSE 114	HGU 28 (STRZ5)	Represents from 4000 m to 7000 m depth within the Strzelecki Group.	The Strzelecki Group was arbitrarily subdivided by subtracting a 3000 m thick slab from Strzelecki4 (27). The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strzelecki5 ranges in thickness from 2 m to 3134 m.
29	BSE 114	HGU 29 (STRZ6)	Represents from 7000 m to Palaeozoic Basement depth within the Strzelecki Group.	The Strzelecki Group was arbitrarily subdivided and Strzelecki6 represents the remaining Strzelecki Group not already incorporated into overlying layers. The unit extends to the intersection with Palaeozoic Basement (30) at which point it has been clipped.	Strzelecki6 ranges in thickness from 266 m to 4000 m.

Model layer	Inputs and VAF code	Hydrogeological Unit	Geology	Description of generation procedure	Thickness
30	BSE 114	HGU 30 (PALEO)	Represents the Palaeozoic Basement.	Internal GSV grids were used as the foundation for the Palaeozoic (30) HGU. The Palaeozoic surface was then modified in the following ways: BSE (GH, 2012; SKM, 2009) was clipped to the extent of Palaeozoic outcrop and merged with Palaeozoic basement; Basement intersections from Constantine (2009) were used to constrain Palaeozoic basement depth; Strzelecki intersections from (Constantine 2009) were used to limit the upward extent; Interpretations based on isostatic gravity anomalies were used to mould the geometry of troughs; offshore basement surfaces from McLean & Blackman (2013) and Stuart-Smith et al. (2010) were merged together	The Palaeozoic HGU ranges in thickness from 2 m to 262 m.

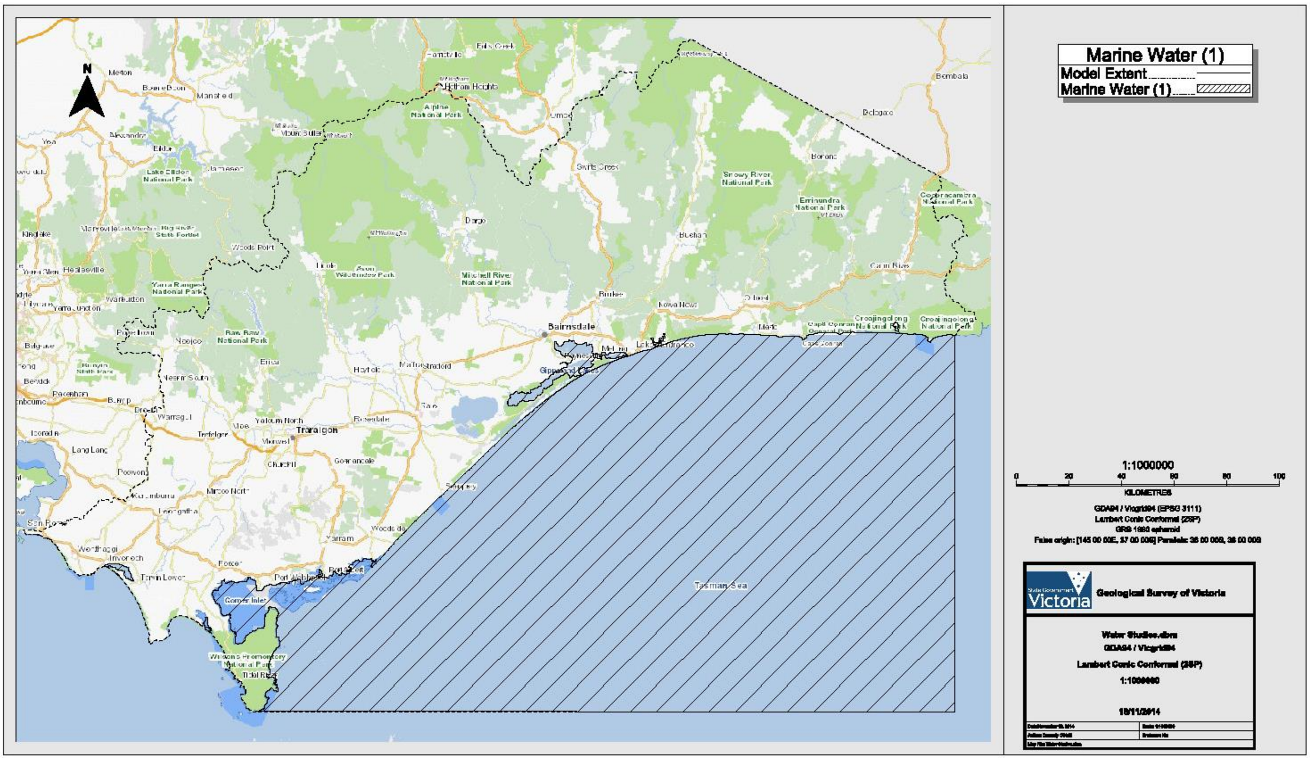


Figure 13 Hydrogeological Unit (HGU) 1 representing the marine waters throughout the offshore portion of the modelled area

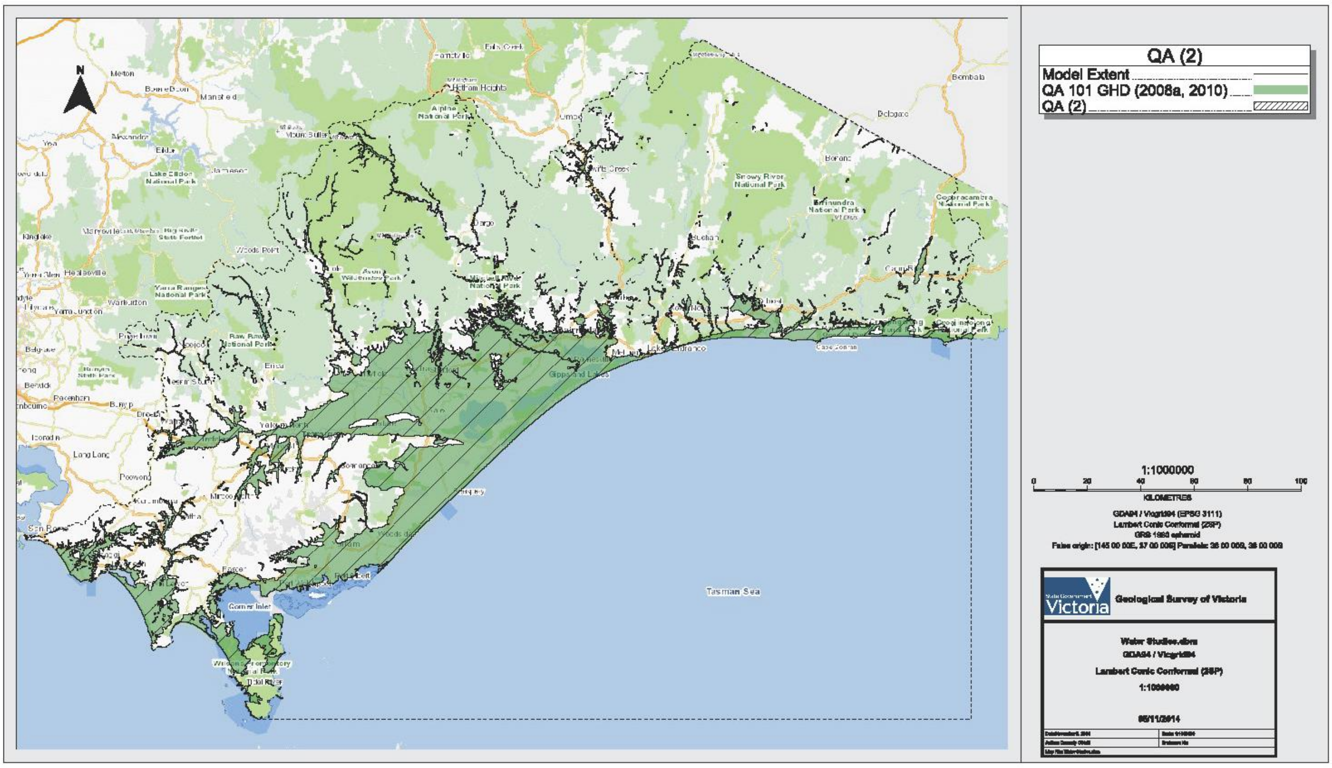


Figure 14 Hydrogeological Unit (HGU) 2 representing the Quaternary Alluvium

2.6.2.3.4 Modelled hydrogeological units

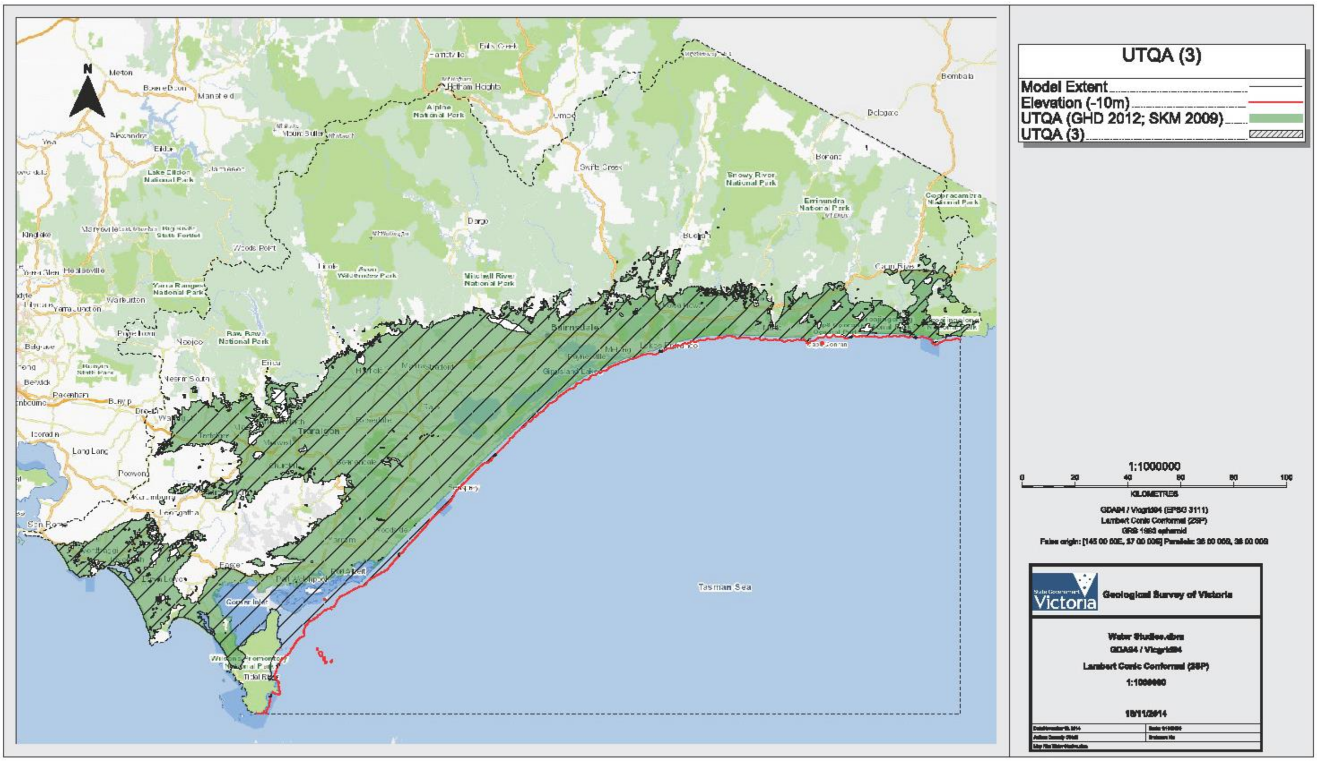


Figure 15 Hydrogeological Unit (HGU) 3 representing the Upper Tertiary Quaternary Alluvium

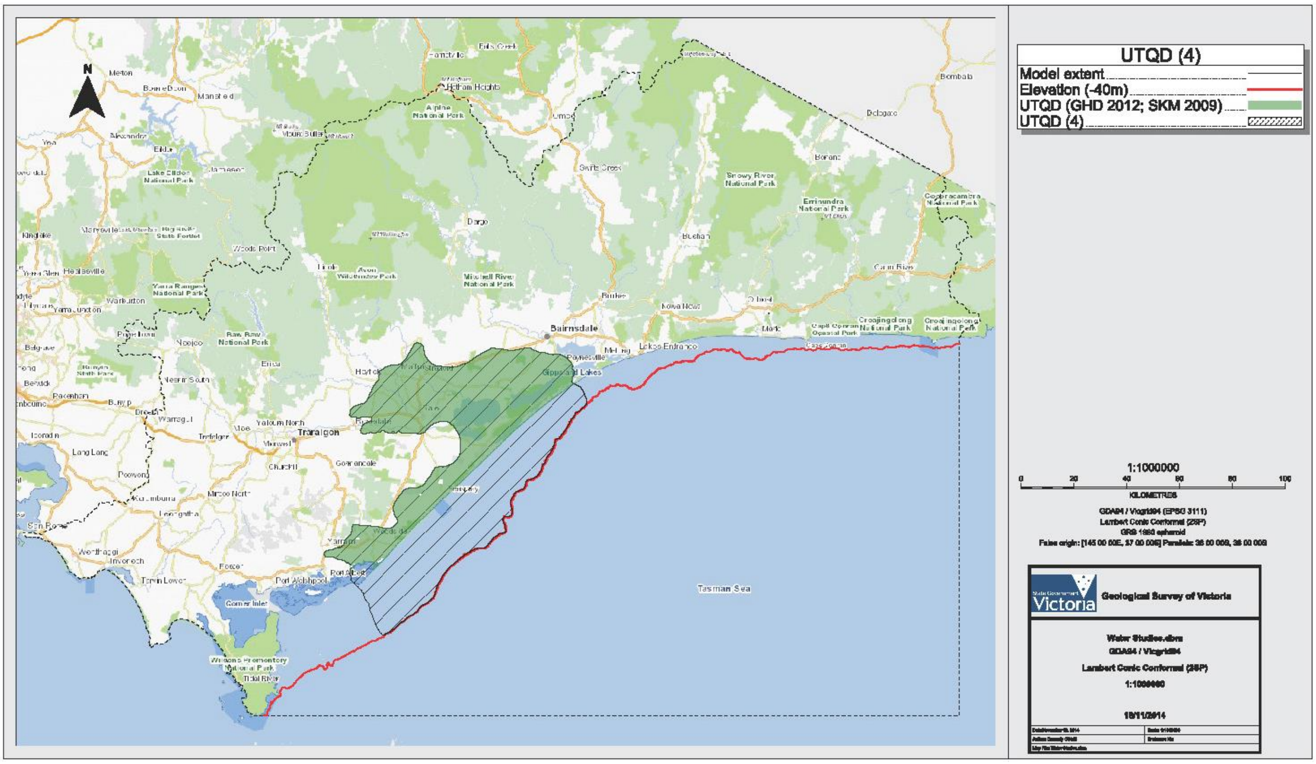


Figure 16 Hydrogeological Unit (HGU) 4 representing the Upper Tertiary Quaternary Aquitard

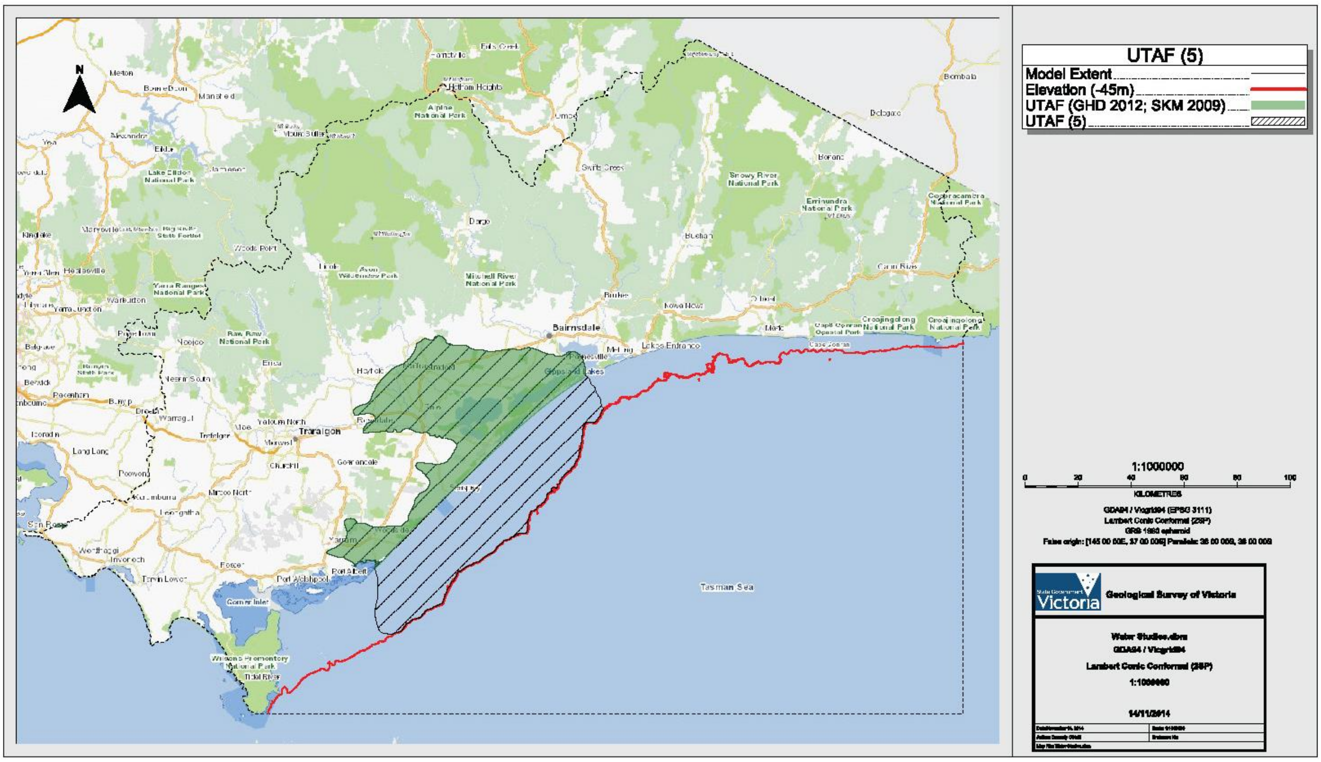


Figure 17 Hydrogeological Unit (HGU) 5 representing the Upper Tertiary Aquifer

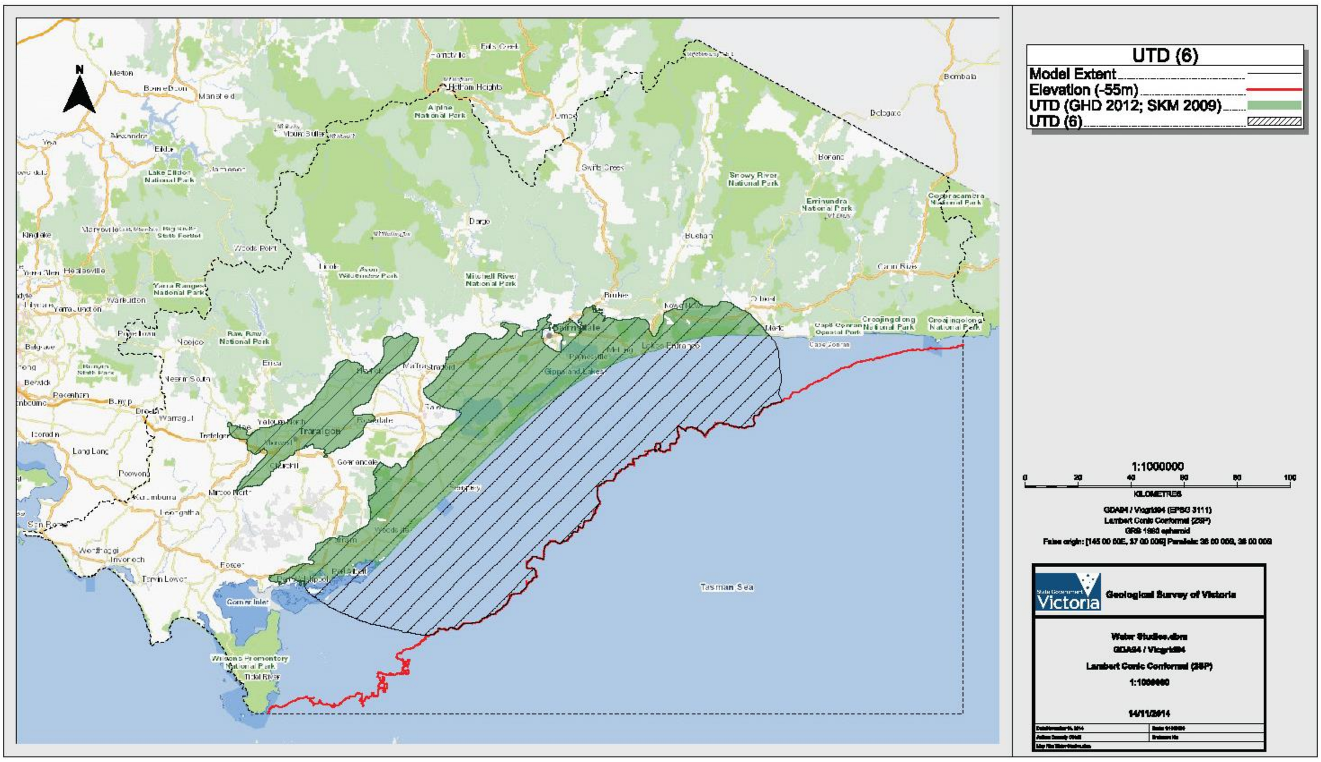


Figure 18 Hydrogeological Unit (HGU) 6 representing the Upper Tertiary Aquitard

2.6.2.3.4 Modelled hydrogeological units

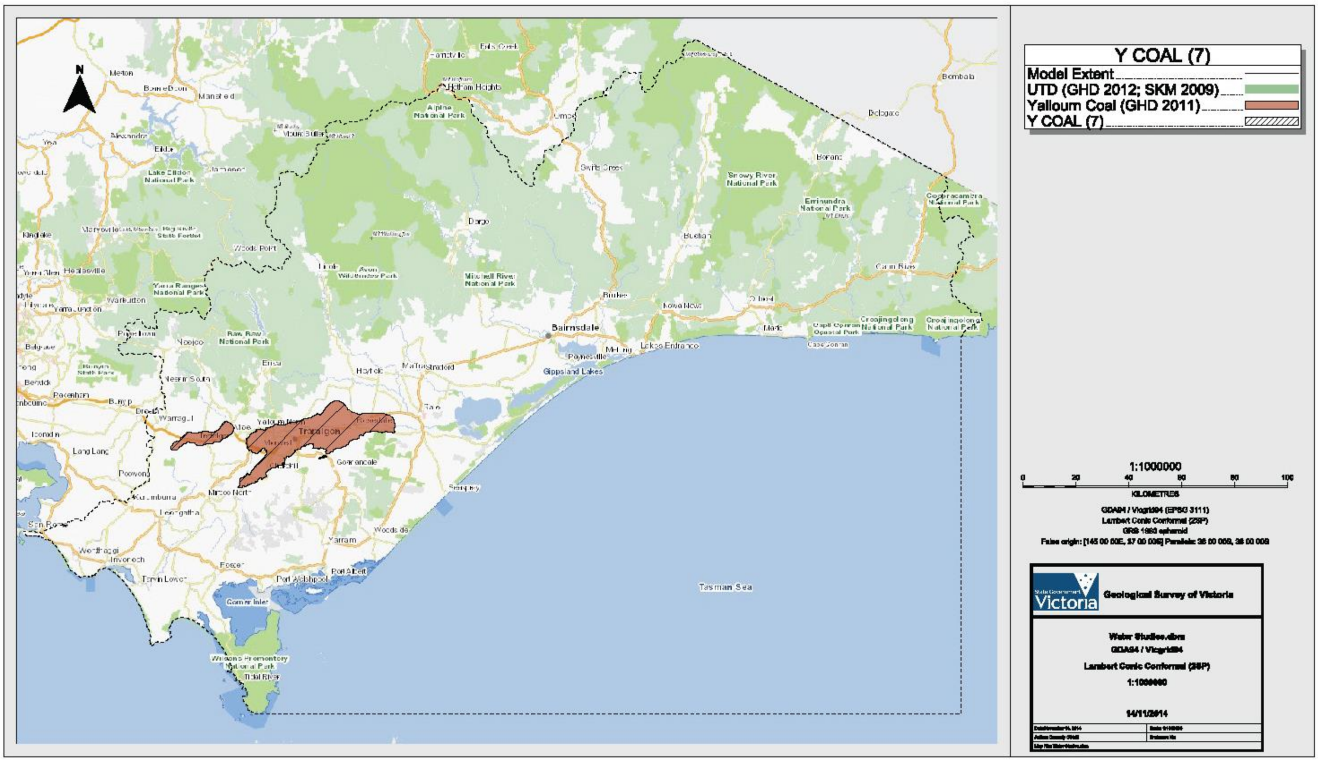


Figure 19 Hydrogeological Unit (HGU) 7 representing the Yallourn Coal seams

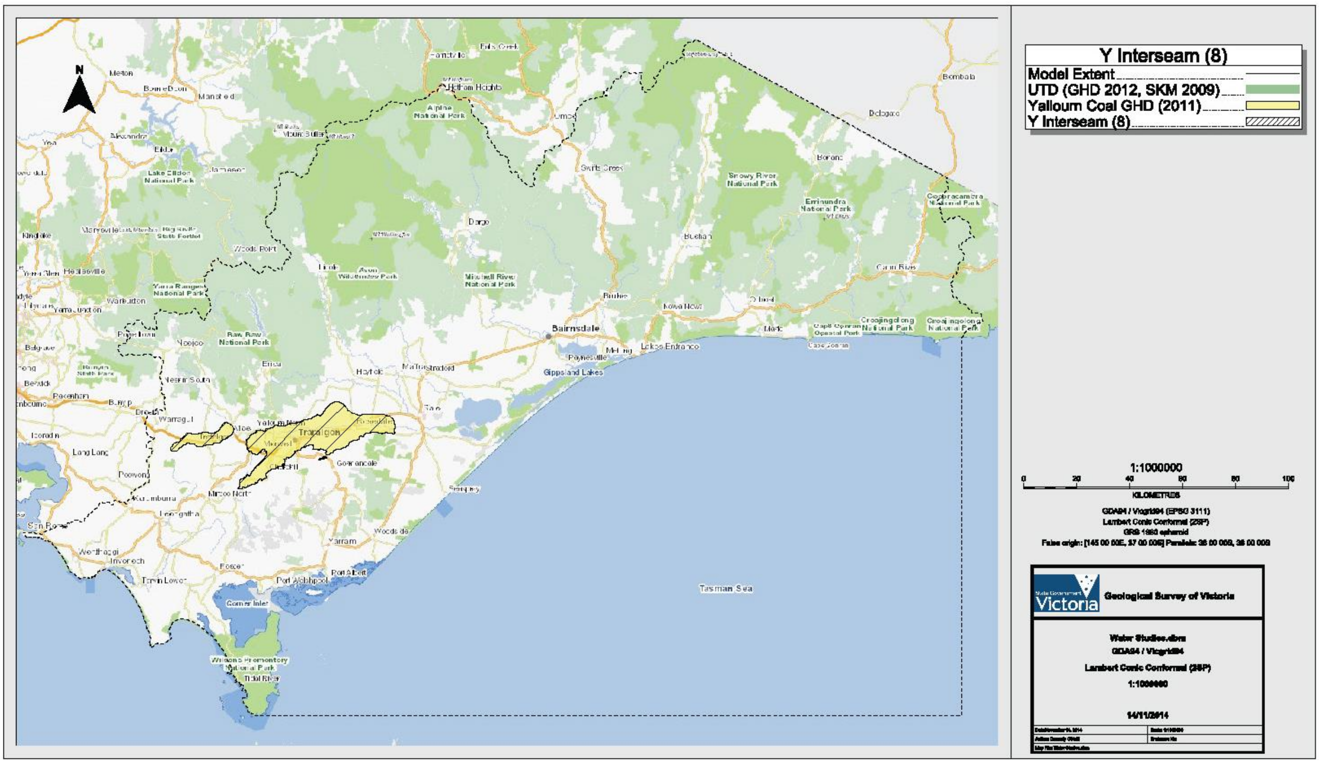


Figure 20 Hydrogeological Unit (HGU) 8 representing the Yallourn interseam

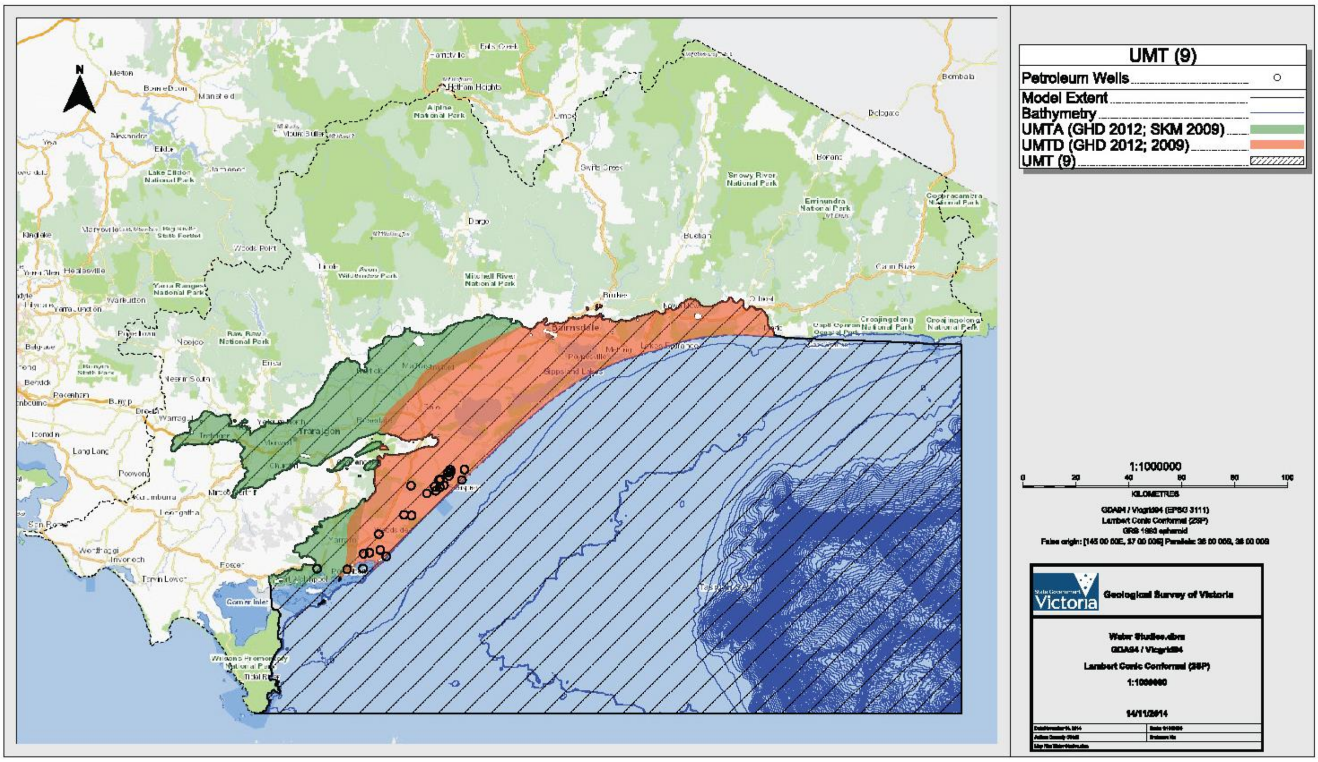


Figure 21 Hydrogeological Unit (HGU) 9 representing the Upper Mid-Tertiary Aquifer and Aquitard

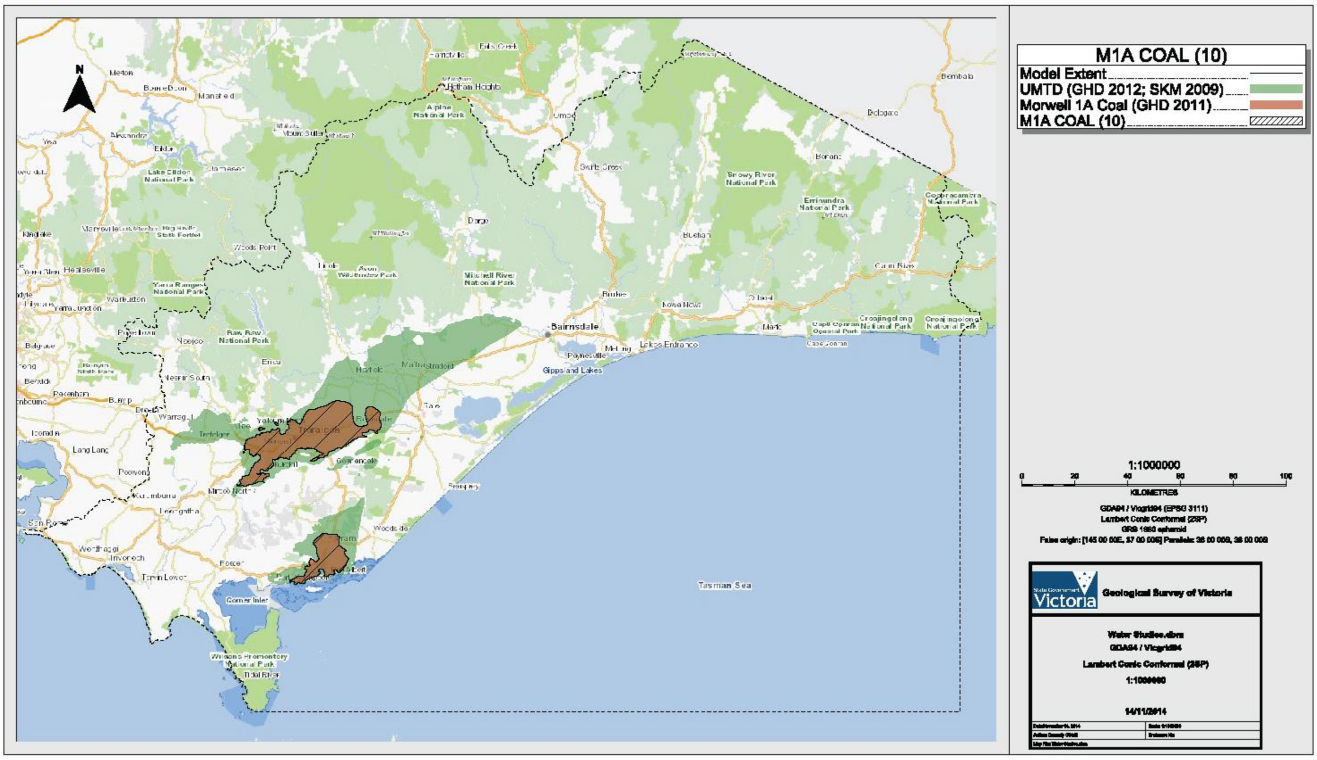


Figure 22 Hydrogeological Unit (HGU) 10 representing the Morwell 1A Coal Seam

2.6.2.3.4 Modelled hydrogeological units

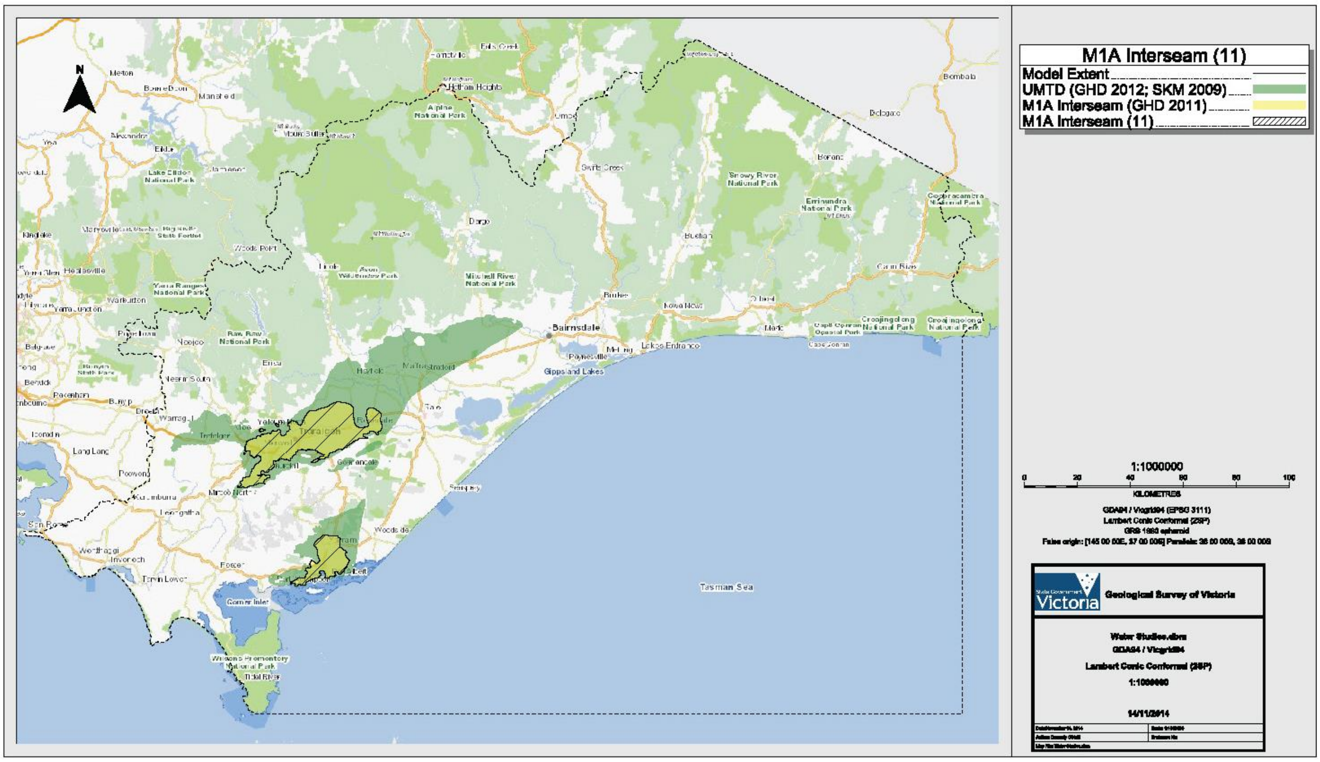


Figure 23 Hydrogeological Unit (HGU) 11 representing the interseam between the Morwell 1A Coal floor and the Morwell 1B Coal roof

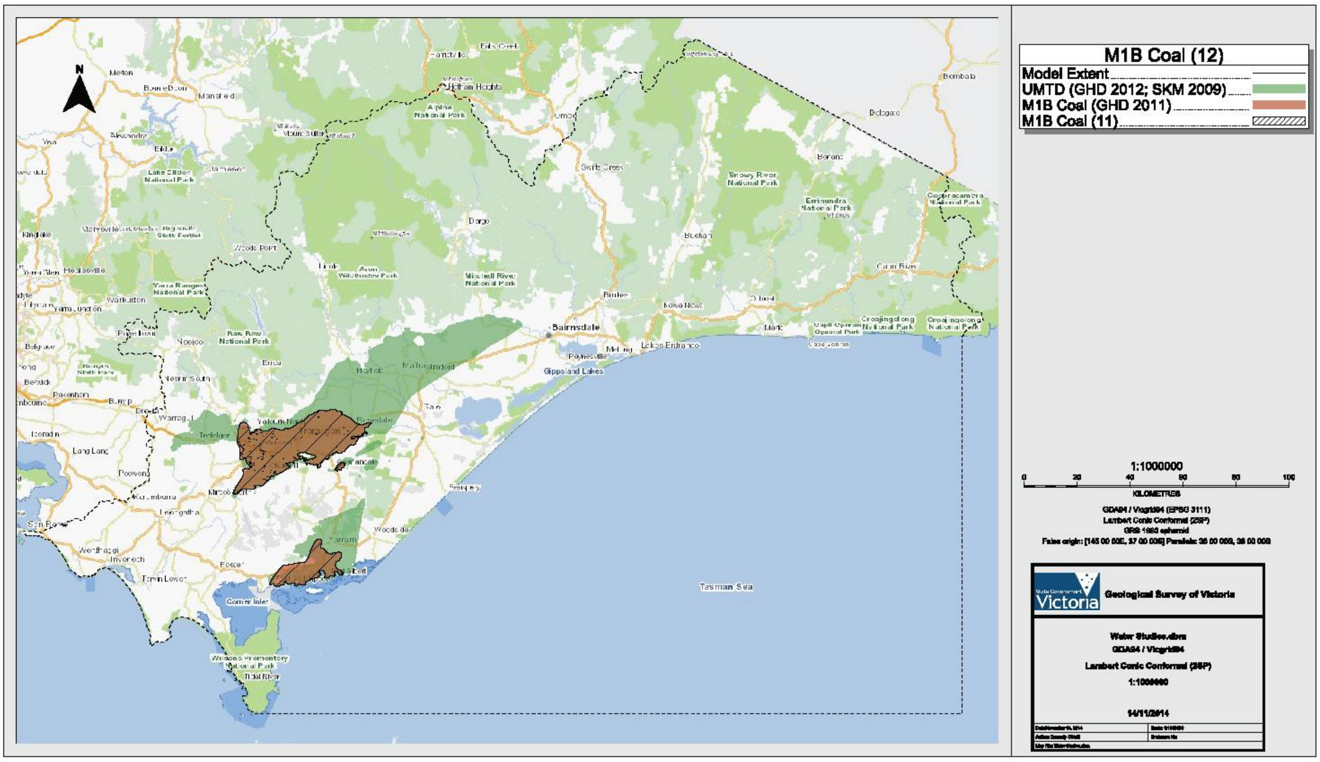


Figure 24 Hydrogeological Unit (HGU) 12 representing the Morwell 1B coal seams

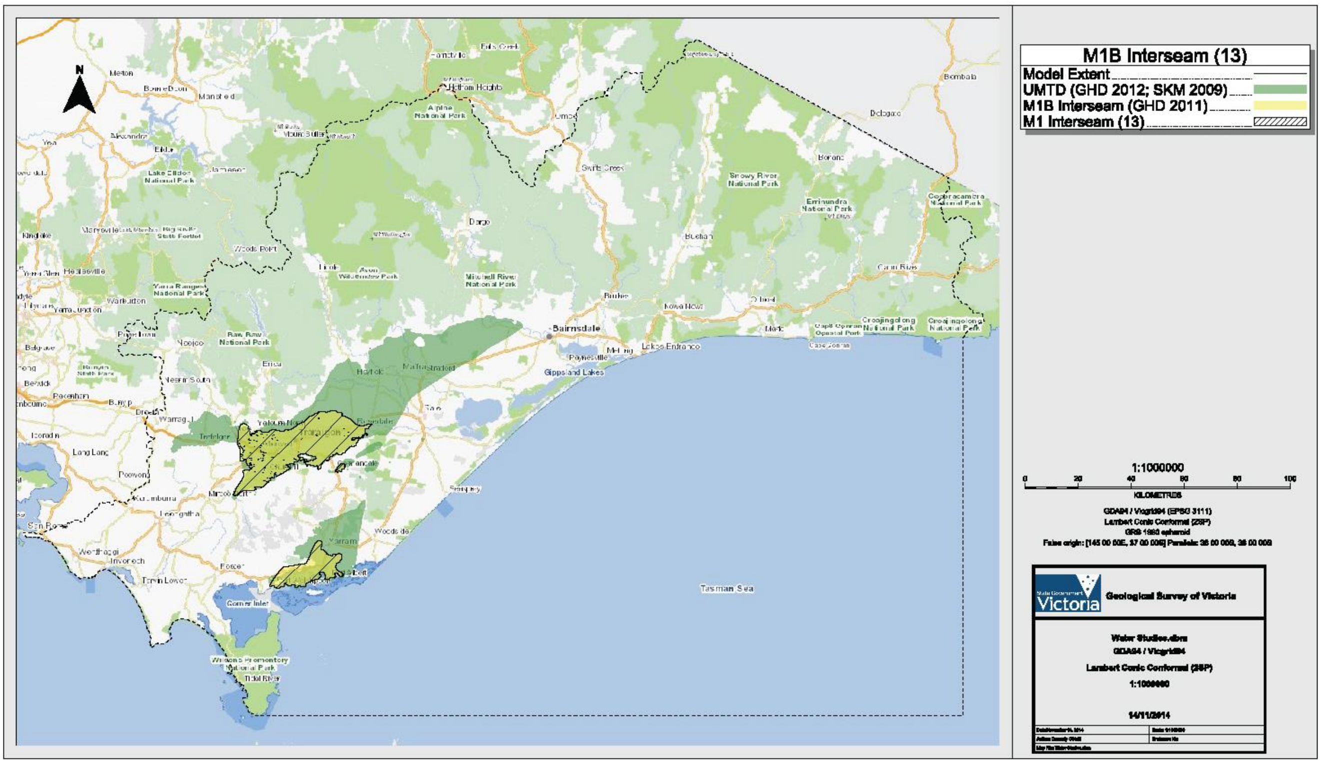


Figure 25 Hydrogeological Unit (HGU) 13 representing the Morwell 1B interseam between the Morwell 1B coal floor and Morwell 2 coal roof

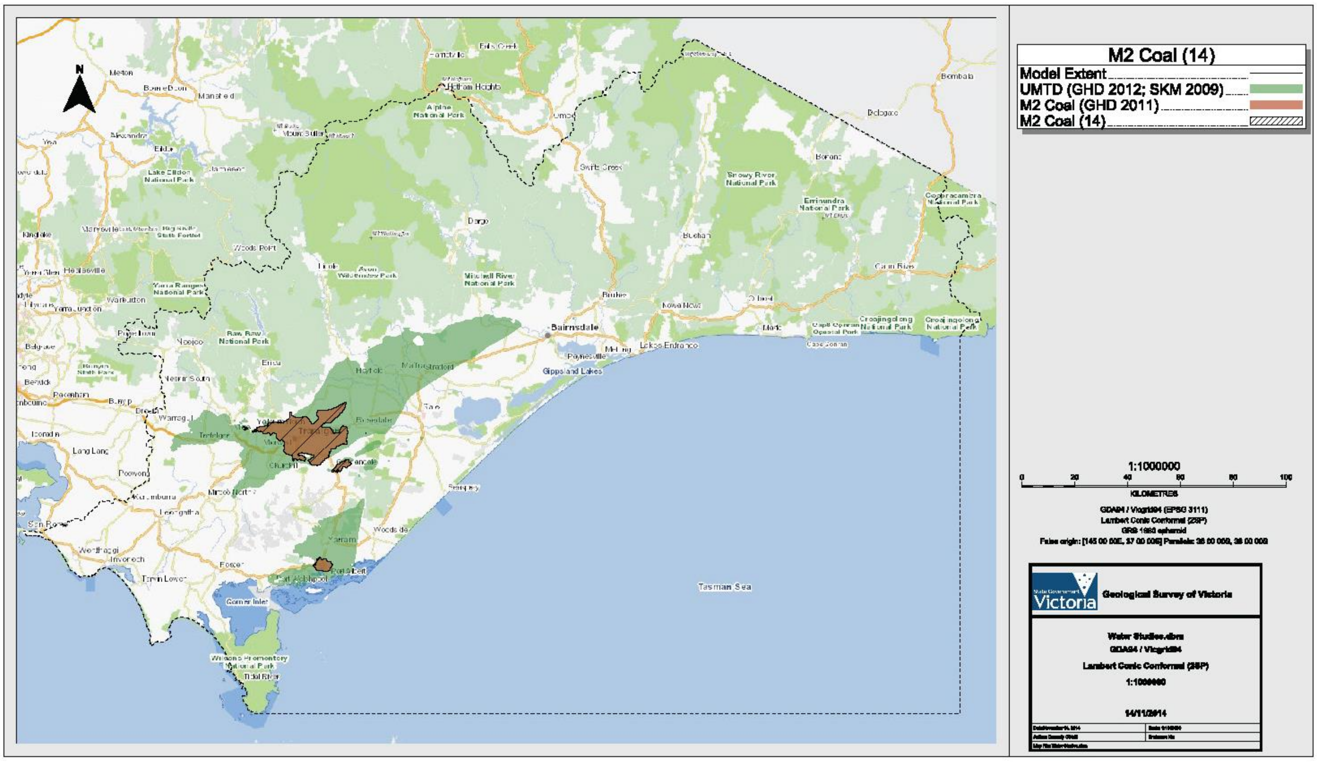


Figure 26 Hydrogeological Unit (HGU) 14 representing the Morwell 2 Coal Seam

2.6.2.3.4 Modelled hydrogeological units

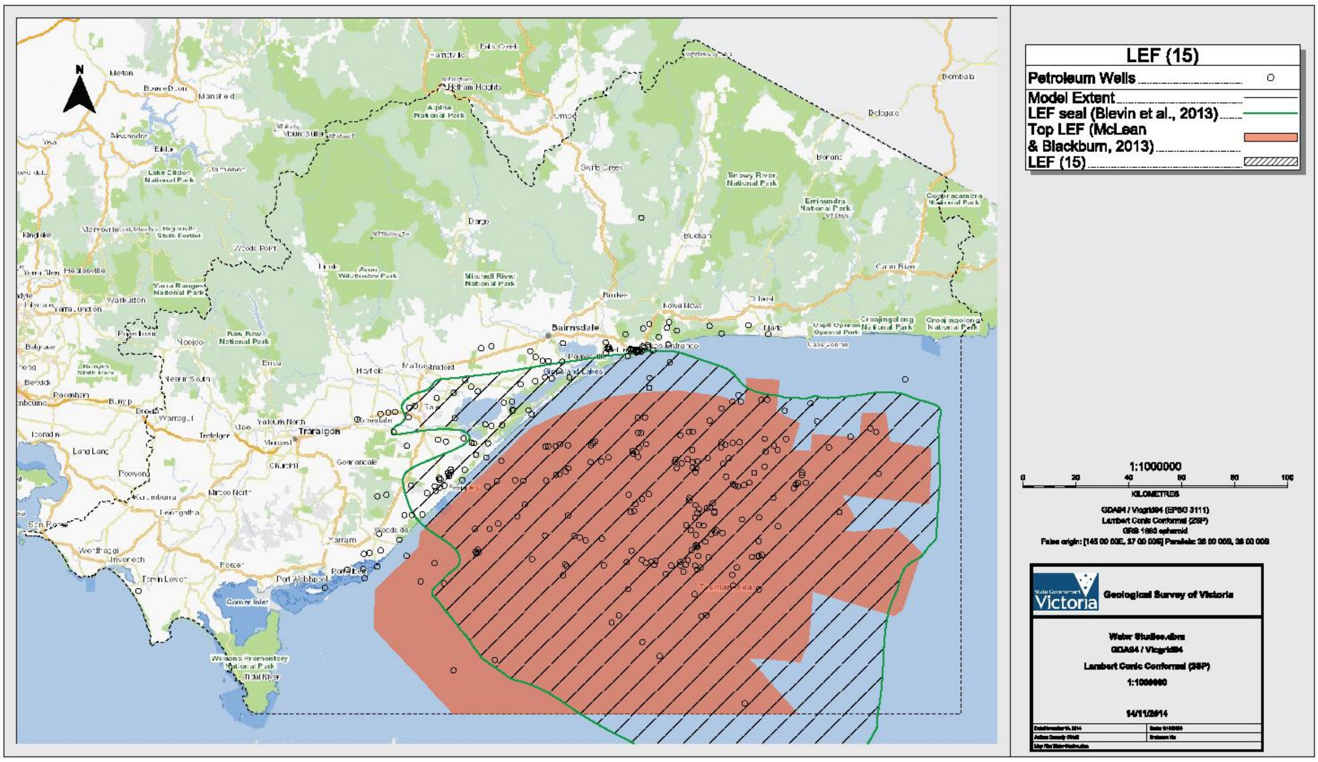


Figure 27 Hydrogeological Unit (HGU) 15 representing the Lakes Entrance Formation

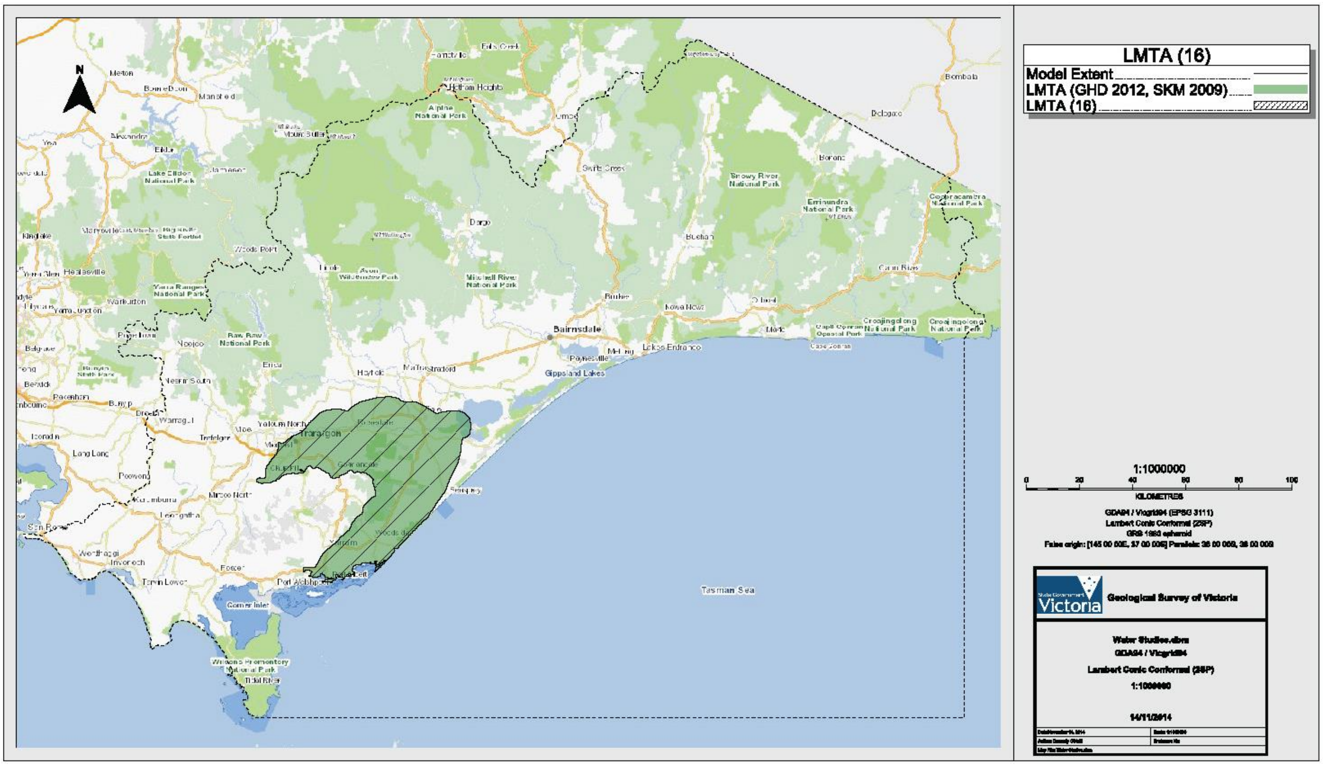


Figure 28 Hydrogeological Unit (HGU) 16 representing the Lower Mid Tertiary Aquifer

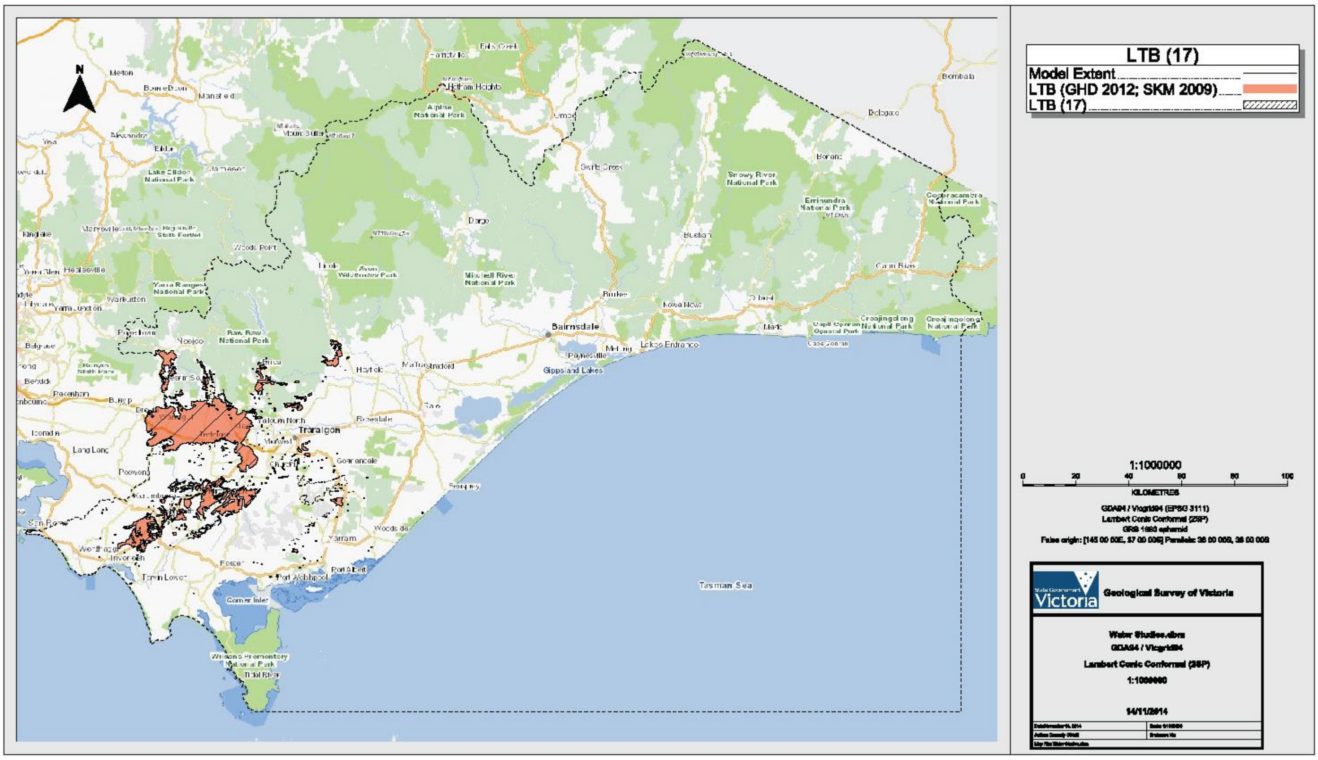


Figure 29 Hydrogeological Unit (HGU) 17 representing the Lower Tertiary Basalts

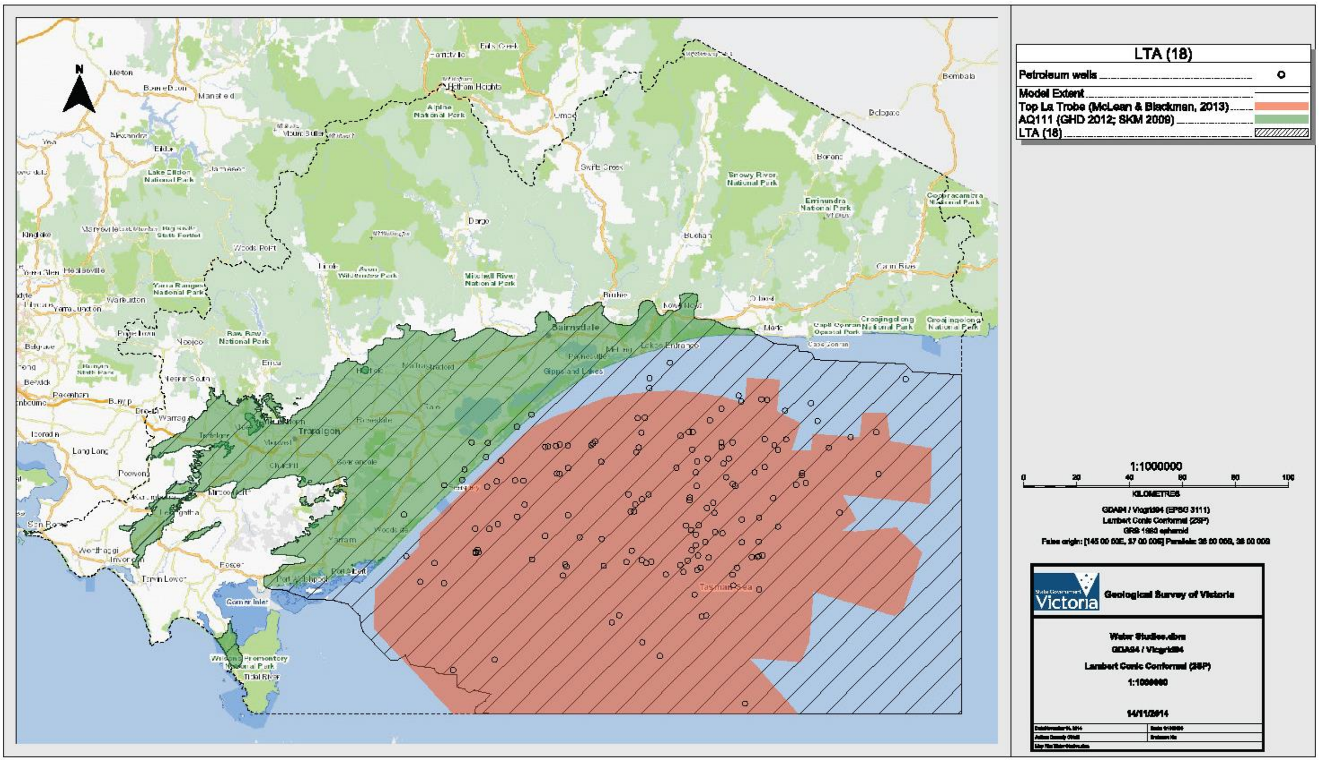


Figure 30 Hydrogeological Unit (HGU) 18 representing the Lower Tertiary Aquifer

2.6.2.3.4 Modelled hydrogeological units

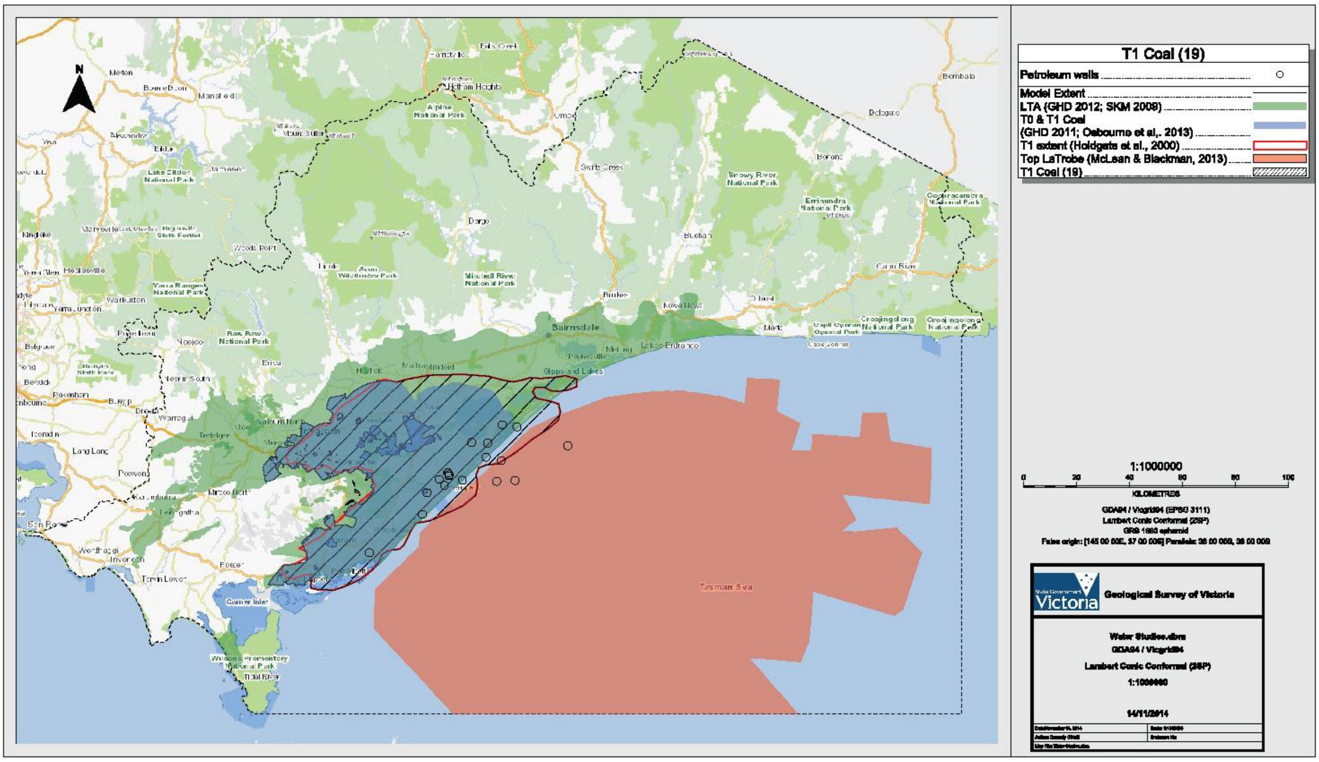


Figure 31 Hydrogeological Unit (HGU) 19 representing the Traralgon T0 and T1 coal seams and T0 inter-burden

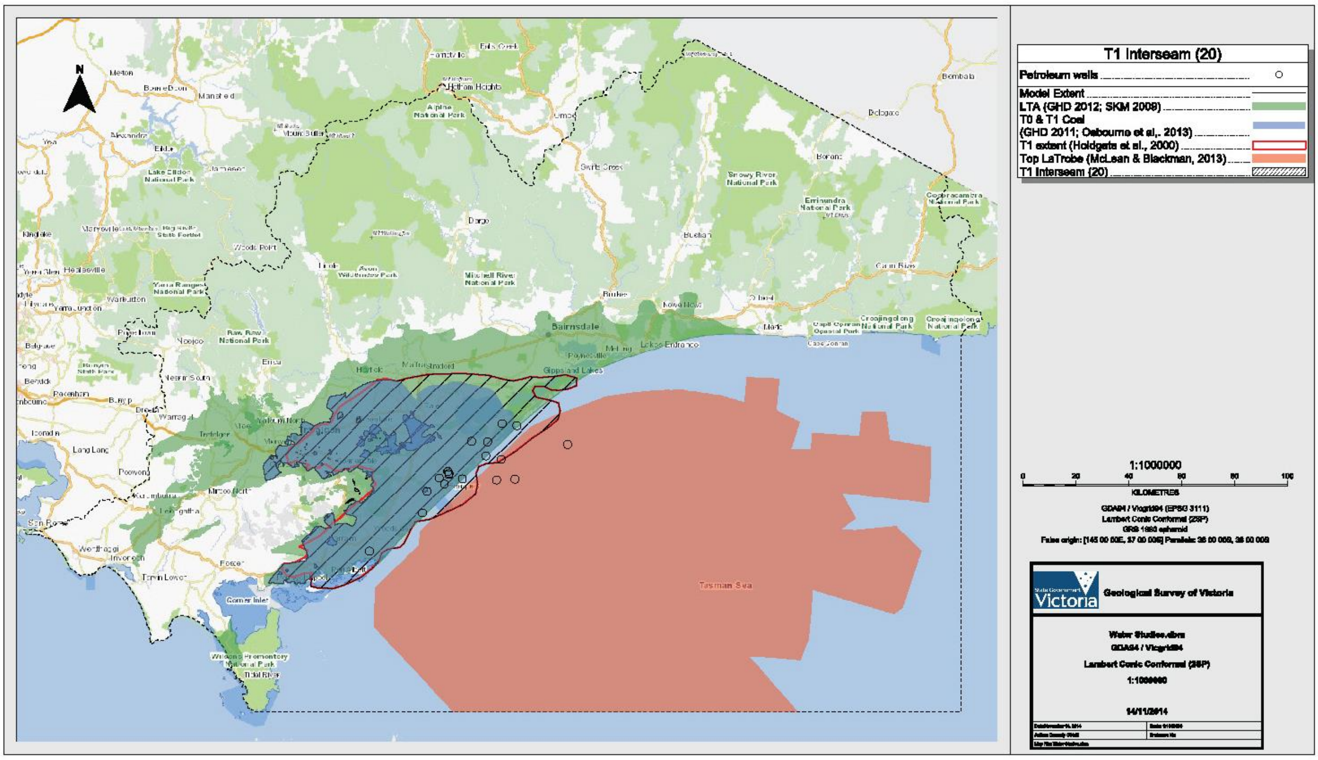


Figure 32 Hydrogeological Unit (HGU) 20 representing the Traralgon T1 aquifer and includes the T1 interseam

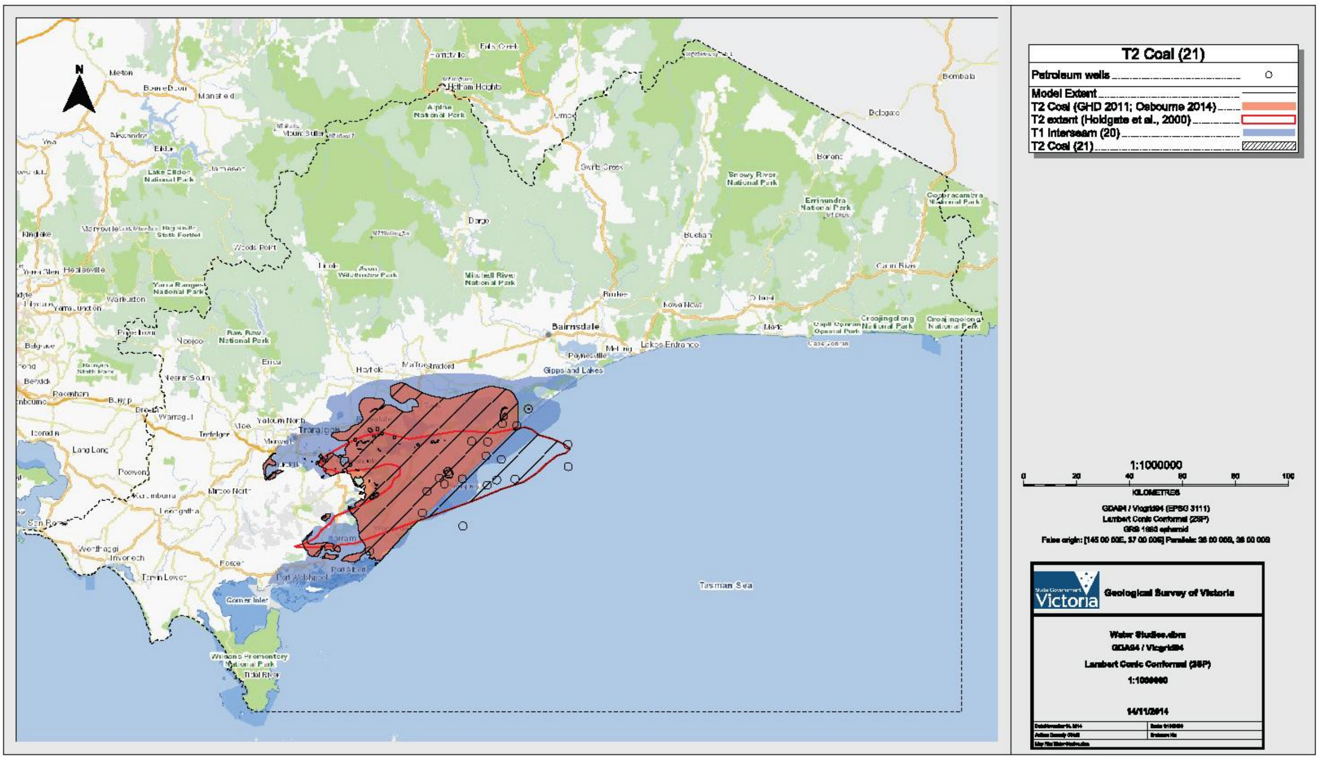


Figure 33 Hydrogeological Unit (HGU) 21 representing the Traralgon T2 coal seams and minor interseams

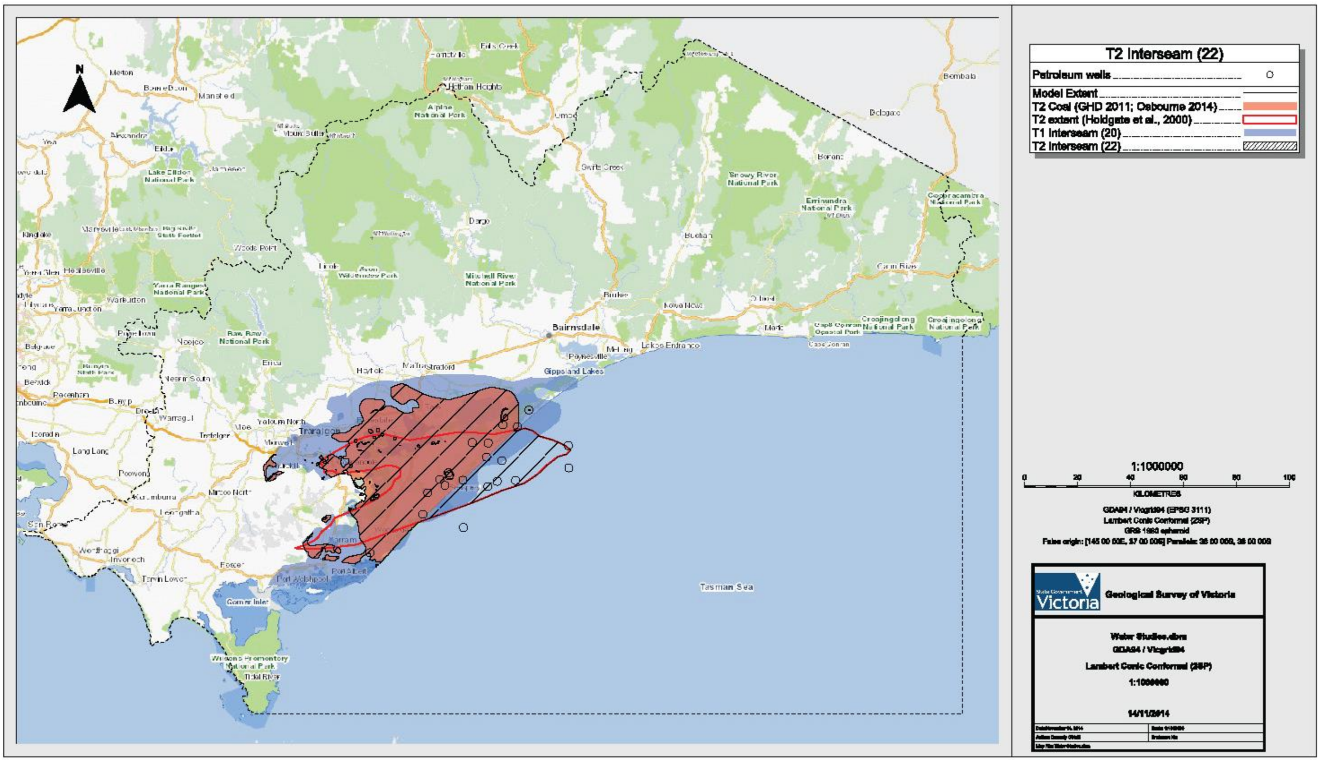


Figure 34 Hydrogeological Unit (HGU) 22 representing the Traralgon T2 inter-burden (aquifer) below the T2 coal seams

2.6.2.3.4 Modelled hydrogeological units

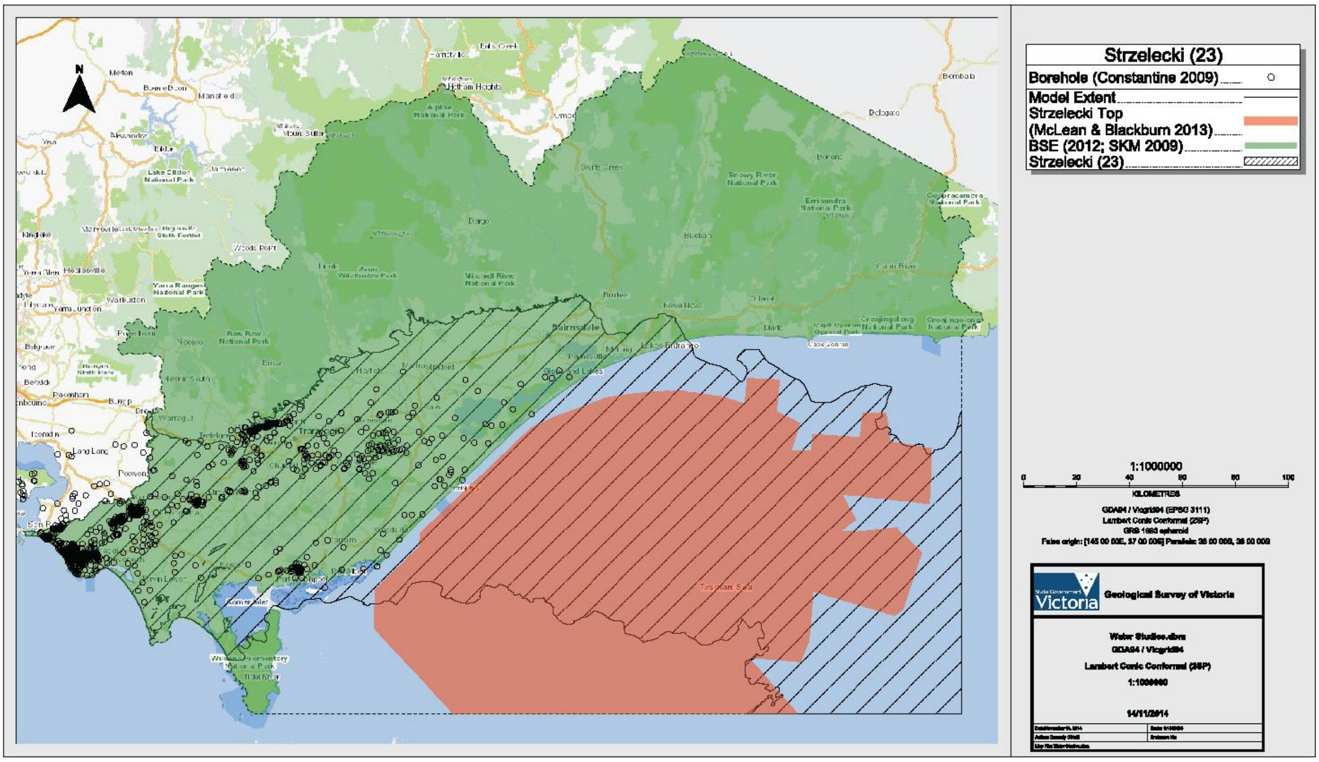


Figure 35 Hydrogeological Unit (HGU) 23 representing the upper 500 m of the Strzelecki Group

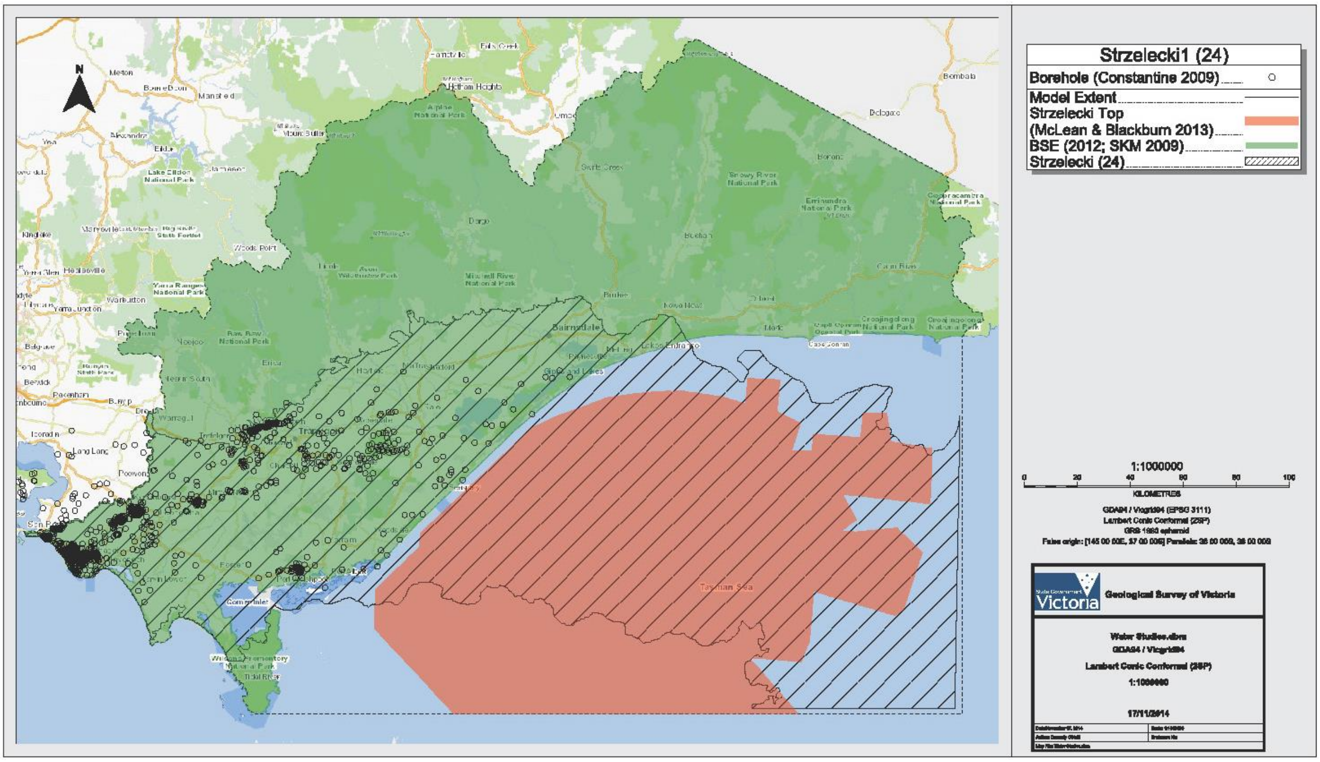


Figure 36 Hydrogeological Unit (HGU) 24 representing from 500 m to 1,000 m depth within the Strzelecki Group

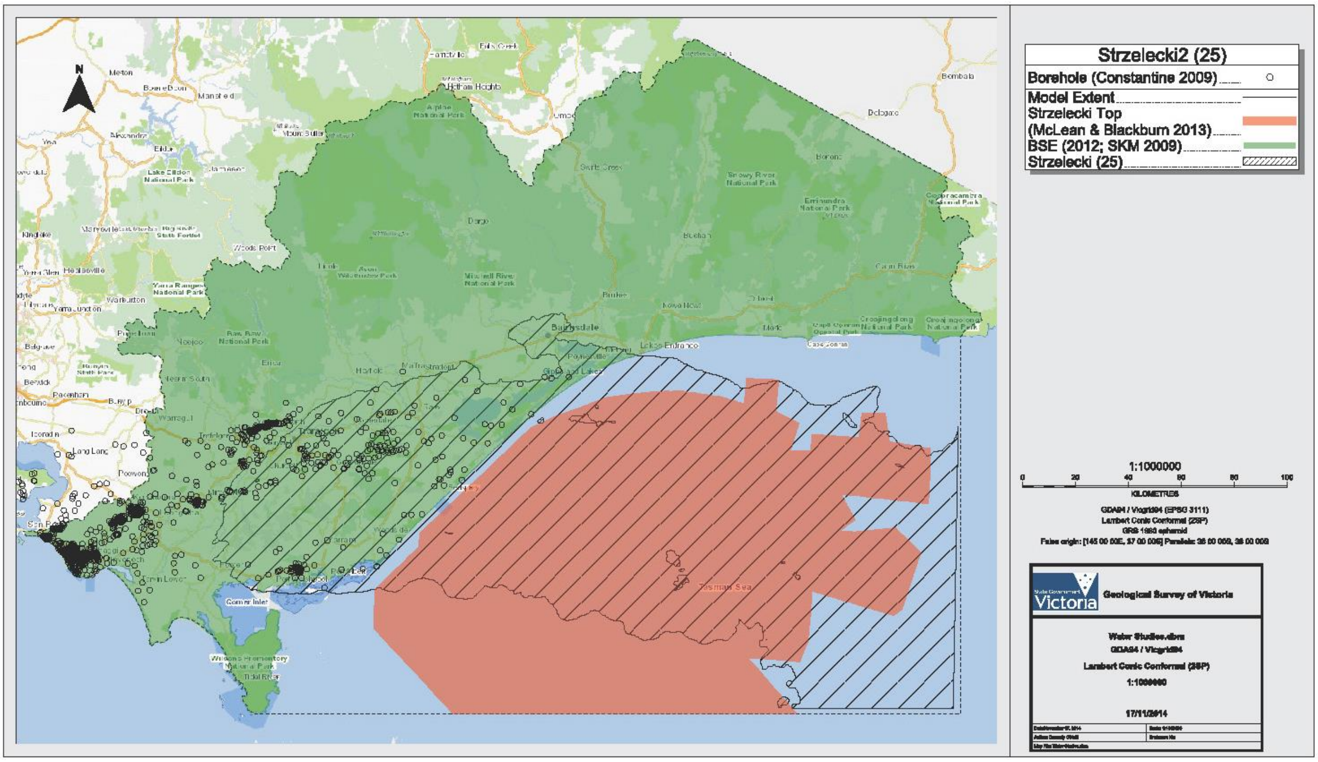


Figure 37 Hydrogeological Unit (HGU) 25 representing from 1,000 m to 2,000 m depth within the Strzelecki Group

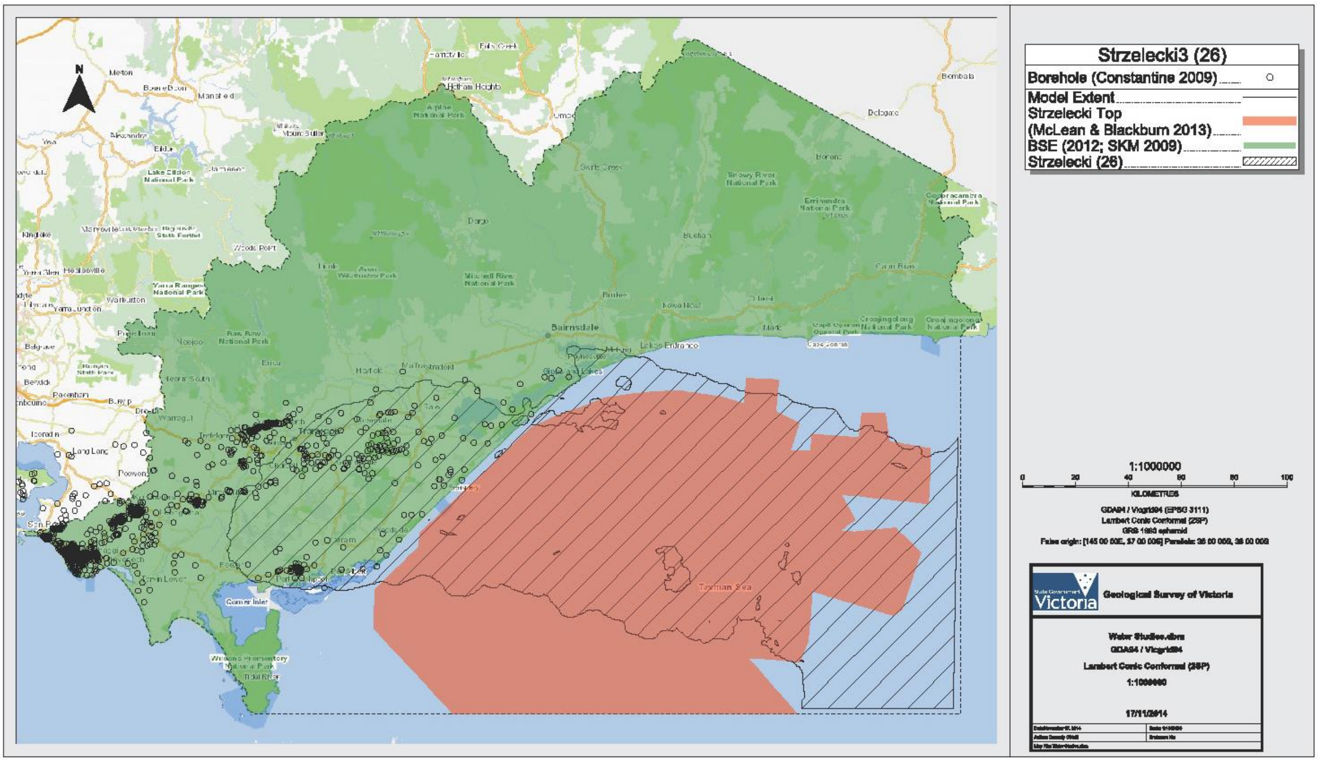


Figure 38 Hydrogeological Unit (HGU) 26 representing from 2,000 m to 3,000 m depth within the Strzelecki Group

2.6.2.3.4 Modelled hydrogeological units

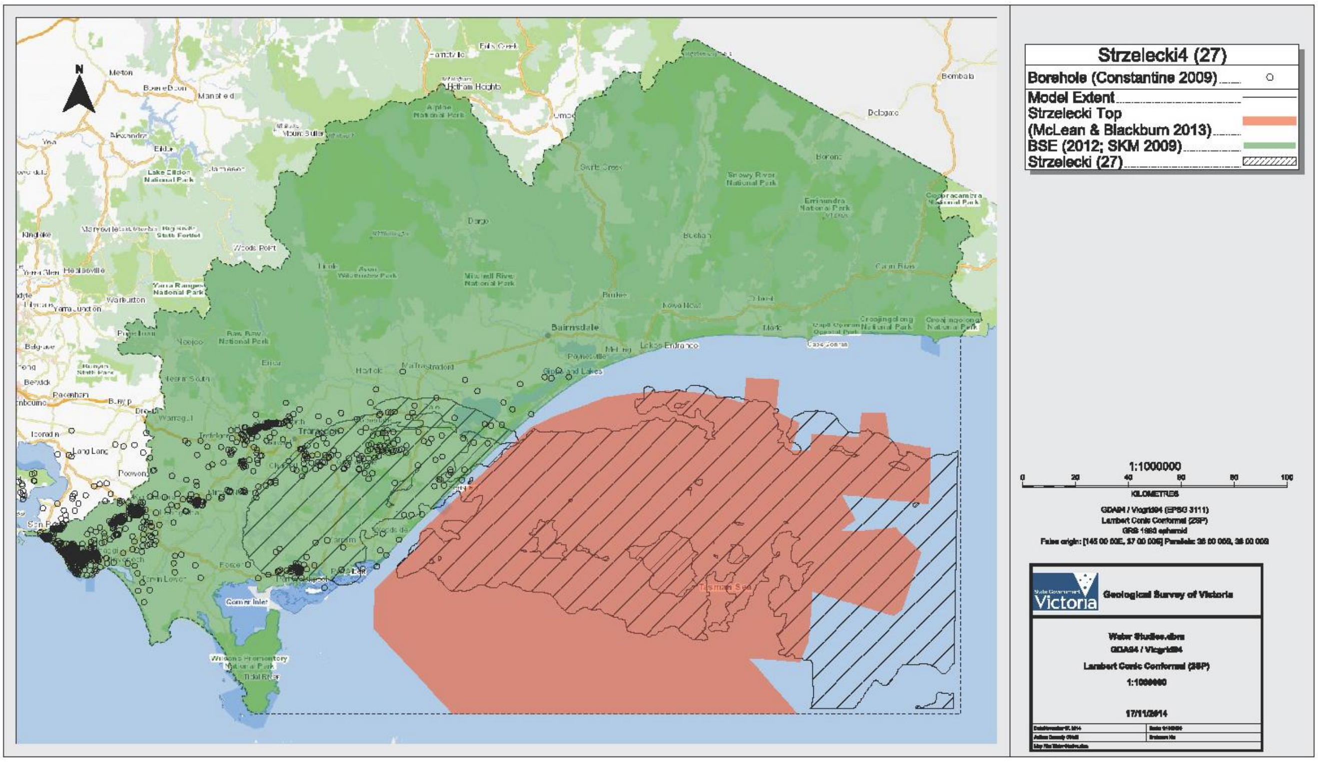


Figure 39 Hydrogeological Unit (HGU) 27 representing from 3,000 m to 4,000 m depth within the Strzelecki Group

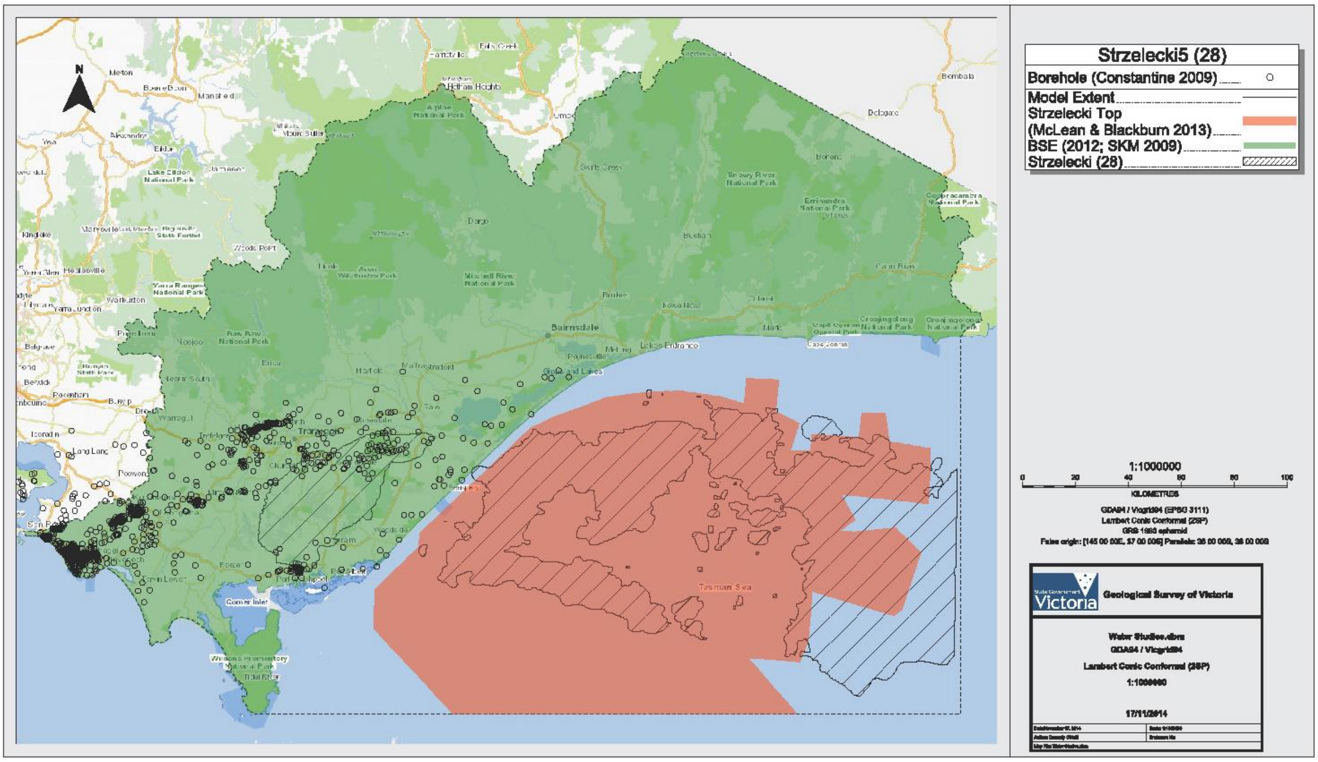


Figure 40 Hydrogeological Unit (HGU) 28 representing from 4,000 m to 7,000 m depth within the Strzelecki Group

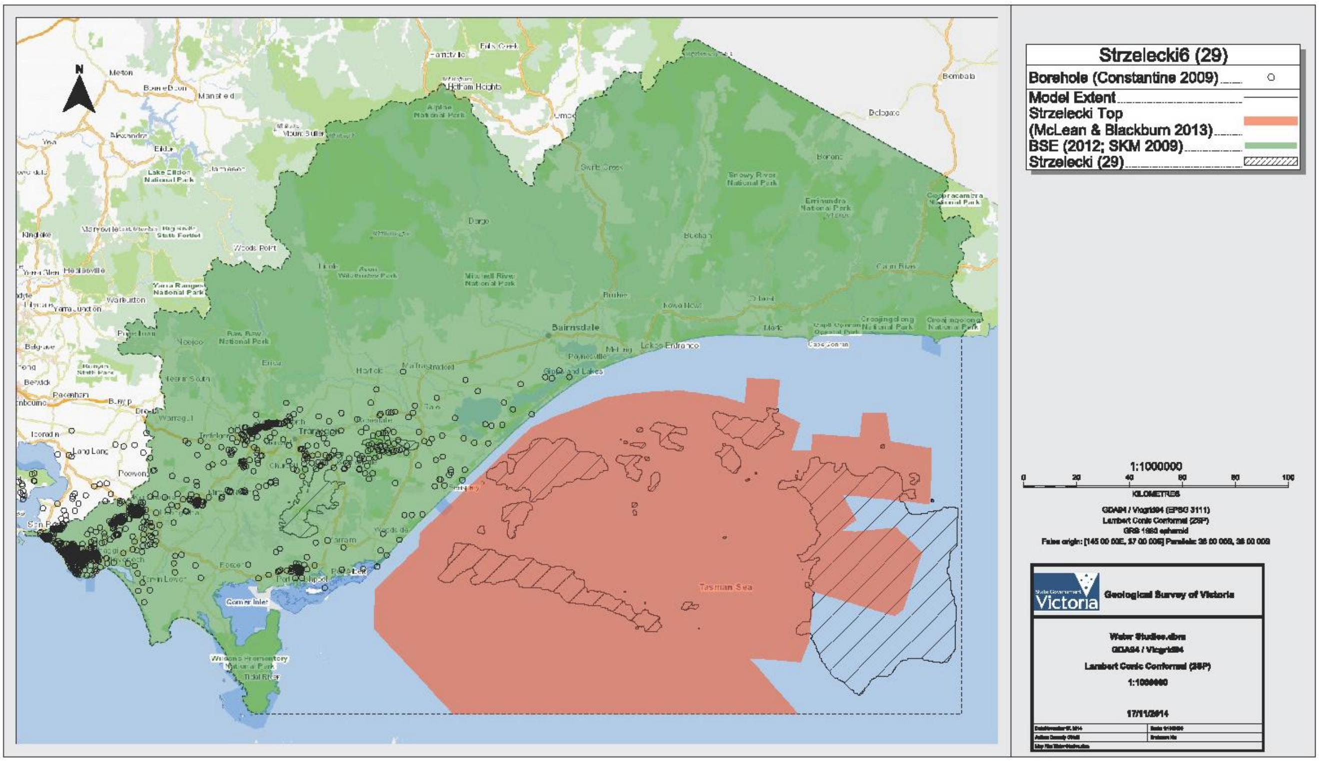


Figure 41 Hydrogeological Unit (HGU) 29 representing from 7,000 m to Palaeozoic Basement depth within the Strzelecki Group

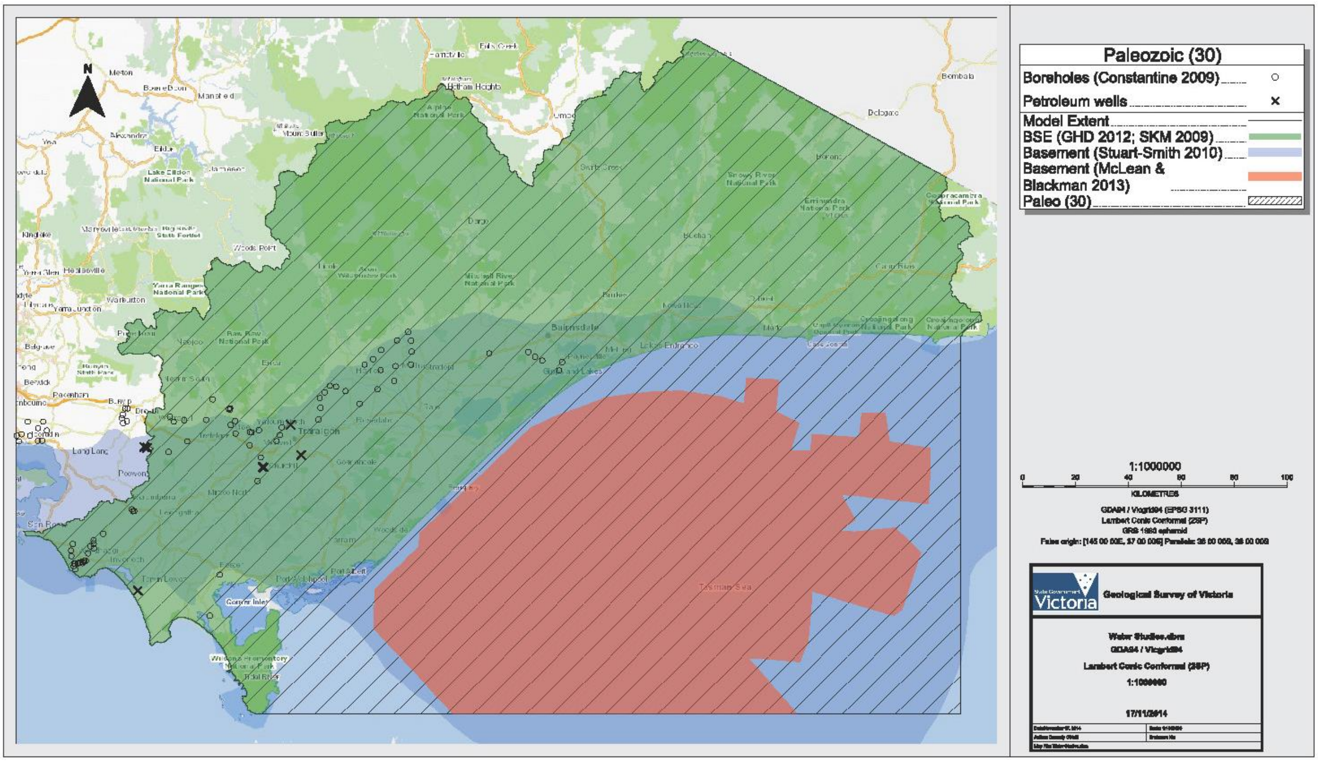


Figure 42 Hydrogeological Unit (HGU) 30 representing the Palaeozoic Basement

2.6.2.3.5 Modelling approach

The modelling tasks involved using an unsaturated biophysical catchment model to generate daily evapotranspiration demands and recharge estimates. This data was then used as input into the distributed groundwater model. As such the simulation procedure was uncoupled. This approach was considered to better represent farming systems and farm practices due to the construct of the unsaturated biophysical catchment model, functions of which are not commonly available in commercial groundwater modelling codes. Importantly this approach enables (1) finer resolution representation of farm management units to be captured and integrated into coarser resolution groundwater models, and (2) a holistic water balance that describes both soil-water-plant interactions and groundwater dynamics.

In addition to the unsaturated and groundwater modelling frameworks, customised software was also developed to assist in the pre- and post-processing of input data and simulation outputs. Each modelling approach is described below.

2.6.2.3.6 Unsaturated modelling software

Modelling of the unsaturated zone was undertaken using the Catchment Analysis Tool (CAT) (Beverly et al., 2005, Beverly, 2009). The CAT model utilises a suite of farming system models linked within a catchment framework with allowance for landscape connectivity and connection to a distributed, multi-layered groundwater model. The farm-scale models account for position in the landscape (topography, soil type, aspect and slope), climate, land use and land management and simulates water balance, nutrient transport and production on a daily time step.

2.6.2.3.7 Groundwater modelling software and solver

Two groundwater modelling frameworks have been deployed, namely:

- USGS MODFLOW-2005: A uniform rectilinear grid of the model domain was constructed and incorporated into the USGS source code version of MODFLOW-2005 finite difference modelling software. This model has provided predictions at a scale consistent with previous regional scale assessments.
- Groundwater Vistas: The commercial software version of MODFLOW-2005 embedded in Groundwater Vistas was used to independently check results derived using the USGS source code version of the MODFLOW-2005 finite difference modelling software. This was deemed prudent as Groundwater Vistas has implemented modifications to the solver algorithms enabling convergence to be met based on outer iterations only, the impacts of which required cross-checking with predictions derived using the original USGS version. The user interface of Groundwater Vistas aided visualisation and interrogation of model input data and simulation results.

Both models were developed using the same spatial and temporal data inputs. The groundwater solver used was the preconditioned conjugate gradient (PCG2) routine.

It is recognised that the adoption of a distributed, multi-layered groundwater model in this application is a complex groundwater model that has been developed for the Bioregional Assessment programme and differs philosophically from the use of a simplified Analytical Element

(AE) model approach as applied in some other assessments. The AE models have been deliberately quite simple to enable fast convergence as required for uncertainty analysis that evaluates the plausible model input parameter space to produce a series of probabilistic predictions. Traditionally the AE models do not account for sloping aquifers and are not fully distributed. In this application, the functionality of the distributed modelling approach was considered essential to simulate the expansion of mine activities and associated spatial and temporal variations. The traditional calibration procedure produces a single prediction in a deterministic fashion from an optimised parameter set. However, uncertainty analysis can be undertaken using this form of deterministic model through the adoption of calibration constraints and post-posterior parameter sampling given sufficient computer resources.

2.6.2.3.8 Model complexity

The complexity of the Gippsland region groundwater model is consistent with the 'Impact Assessment' class described by Middlemis (2000). Based on a model appraisal the developed model conceptualisation is on average assumed to have moderate complexity and is suitable for predicting the impacts of proposed developments or management policies. This is further supported using the more recent Australian Groundwater Modelling Guidelines (Barnett et al., 2012) which adopts a Confidence Level Classification.

The Confidence Level Classification is a cornerstone of the national guidelines and is used to indicate the reliability of model predictions based on a number of criteria related to the available data with which the model is conceptualised and calibrated, the manner and accuracy of calibration and the manner in which the predictions are formulated. The assessment criteria are summarised in Table 4.

Three confidence level classes are defined with Class 1 being the lowest confidence and Class 3 the highest. On assessing the various relevant criteria as reported in Table 5, it is considered that the model should be targeted as Class 2 which is appropriate for assessing regional groundwater impacts. Factors limiting higher confidence include the limited availability of data in the offshore parts of the model domain and the absence of any historic coal seam gas or tight and shale gas developments and hence predictive scenarios include stresses and associated impacts that have yet to be demonstrated.

Table 4 Summary of Confidence Level Classification criteria adopted in the Australian Groundwater Modelling Guidelines (Barnett et al., 2012)

Class	Data	Calibration	Prediction	Indicators
1	Not much Sparse No metered usage Remote climate data	Not possible Large error statistic Inadequate data spread Targets incompatible with model purpose.	Timeframe >> calibration Long stress periods Transient prediction but steady-state calibration Bad verification.	Timeframe > 10x Stresses > 5x Mass balance > 1% (for single 5%). Properties <> field. Bad discretisation. No review.
2	Some Poor coverage Some usage information Baseflow estimates	Partial performance. Long-term trends wrong. Short time record. Weak seasonal replication. No use of targets compatible with model purpose.	Timeframe > calibration. Long stress periods. New stresses not in calibration. Poor verification.	Timeftame = 3-10x Stresses = 2-5x Mass balance < 1% Some properties <> field measurements. Some key coarse discretisation. Review by hydrogeol.
3	Lots Good aquifer geometry Good usage information Local climate information K measurements Hi-res DEM	Good performance stats. Long-term trends replicated. Seasonal fluctuations OK. Present day data targets. Head and flux targets.	Timeframe approx. calibration. Similar stress periods. Similar stresses to those in calibration. Steady-state prediction consistent with steady-state calibration. Good verification.	Timeframe < 3x Stresses < 2x Mass balance < 0.5% Properties approx. field measurements. Some key coarse discretisation. Review by modeller.

Table 5 Gippsland Model appraisal based on the abbreviated guideline (Table 4)

Class	Data	Calibration	Prediction	Indicators
1				X Timeframe > 10x
2	X - some	X – partial performance	X timeframe > calibration	
3				

2.6.2.3.9 Model simulation period

Groundwater recharge in southern Australia is strongly correlated with annual rainfall. This is particularly true when the seasonal rainfall pattern follows that established by the long-term trend. In this condition most rainfall occurs during cold wet winters and in hot dry summers.

When evaluating the steady-state condition it is useful to adopt a period that has stable and consistent climate and land use over time. Such a period allows for an assessment of a quasi-equilibrium condition that is ultimately realised between surface water and groundwater. This approach was adopted as the basis of a steady-state groundwater model.

Choosing a representative annual daily climate series that best represents the long-term, zero trending climatic conditions from historical records, and which is supported by adequate and available calibration data within the same time period, is an essential part of constructing a steady-state simulation. Using this approach the representative steady-state condition was based on 1970 climatic conditions, during which no groundwater extractions were assumed. This initial state was selected to represent predevelopment conditions, as post-1970 historic groundwater pumping in the region (on and offshore) had not achieved a quasi-equilibrium response as evidenced by available groundwater hydrograph trends.

The transient simulation period was from 1970 to 2012. This period captures both pre-mine development and a range of varying climatic conditions, including above average wet and dry sequences. The 1970 starting date enables the incorporation of historic groundwater extraction data into the model and provides sufficient lead time for the groundwater model to minimise the impact of initial conditions on model predictions associated with the period of interest, namely the calibration/validation period of 2000 to 2012.

2.6.2.3.10 Model stress periods

The transient calibration period has been formulated with annual stress periods for the period 1970 to1990, and monthly stress periods throughout the 1991 to 2012 calibration/verification periods. The model stress periods were based on adequately capturing historical onshore and offshore extractions, specifically the Latrobe Valley coal mines and offshore oil and gas production wells. To this end, pre-1990 stress periods were assigned as annual within which 12 time-steps were adopted. For the more recent post-1990 calibration/verification period, the stress period was based on representing seasonal water level oscillation and extractions data. As such, monthly time-steps were adopted post-1990. This temporal resolution was also considered adequate to enable an assessment of the potential impacts of water changes on water dependent ecosystems. It must be noted that throughout the simulation daily data was used in the generation of recharge and potential groundwater evapotranspiration stress periods.

2.6.2.3.11 Model groundwater extractions

Time series groundwater extraction data was sourced from various independent data sets, namely:

- Southern Rural Water – This data includes groundwater bore locations, bore construction date, entitlement and metered usage.
- GHD mine models – Pre-existing simulation model well files sourced to provide site specific groundwater extractions associated with the Latrobe Valley coal mines (GHD, 2011a, GHD, 2011b).
- EcoMarkets data – This data set captured the groundwater usage information incorporated in the East Gippsland and West Gippsland groundwater models developed by GHD Pty Ltd (GHD, 2010a, 2010b) as part of the ecoMarkets project commissioned by DSE in 2008.
- Stock and domestic – Victorian state-wide stock and domestic data was provided by DSE and included location, completion date, top of screen and annual extraction volume.

- Offshore extractions – Volume equivalent groundwater extractions associated with offshore oil and gas operations were sourced from Hatton, et al. (2004) and Varma, et al (2012).

All bores were assigned to aquifers according to the following criteria (in order of preference):

- as defined by the source of any historical abstraction data
- based upon bore construction (screen depth) information in conjunction with assigned GMU
- based upon bore construction (screen or bore depth) information
- bores without any GMU or construction data were assigned to the upper most (water table) aquifer.

A dataset for estimating annual groundwater use from all bores, in mega litres per year (ML/year), was compiled using the procedure outlined in Section 1.5.1.2.1 of product 1.5 for the Gippsland Basin bioregion. Limited monitored groundwater usage data was available for East Gippsland CMA bores from 1970 to 1990, but a more complete dataset was available for West Gippsland CMA bores. To address the data deficiency, the annualised West Gippsland CMA groundwater usage trend derived from 1970 to 1990 was assigned to East Gippsland CMA bores with missing data. Bore construction dates were used to ensure that extractions were assigned post-construction. Where data was available, entitlement volumes were used to constrain usage. Importantly, all abstractions within the model domain were forced to exactly match the Water Account usage volumes for the 2003 to 2012 reporting periods as summarised in Table 6.

The modelled average annual groundwater extractions , in giga litres per year (GL/yr), allocated to Groundwater Management Areas (GMA) and Water Supply Protection Areas (WSPA) within the study region are summarised in Table 7. The corresponding time-varying annual extractions are shown in Figure 43; also shown are the contributions from offshore, stock and domestic, mine dewatering, East Gippsland usage (referred to as EG_ML) and West Gippsland usage (referred to as WG_ML).

2.6.2.3.12 Steady-state model conditions

The steady-state calibration conditions represented the 1970 Latrobe Valley pre-development period, during which no groundwater extractions are assigned. Results derived based on the steady-state predictions reflect the long-term equilibrium conditions during which groundwater inputs and stresses are assumed constant throughout time.

2.6.2.3.13 Transient model initial conditions

The initial conditions assigned to the transient model adopted the 1970 pre-development condition represented by the steady-state simulation results.

2.6.2.3.14 Geometry and hydrostratigraphy

The layer thicknesses of each modelled layer are shown in Figure 60 to Figure 88.

Table 6 State Water Accounts (usage ML)

GMA/WSPA	2003–04	2004–05	2005–06	2006–07	2007–08	2008-09	2009–10	2010–11	2011–12
Denison	15,224	6,500	6,680	10,152	6,147	8,385	7,987	3,695	2,992
Giffard	2,719	2,520	3,260	3,719	3,205	3,662	1,717	865	845
Leongatha	648	515	441	625	600	344	158	31	72
Moe	1,098	1,084	990	1,447	1,414	1,081	1,095	191	330
Orbost	464	270	350	540	490	578	333	95	0
Rosedale	15,457	9,920	10,860	7,539	10,678	11,540	11,009	7,543	7,739
Sale	14,680	7,680	10,450	13,358	9,504	11,185	11,094	7,164	6,324
Stratford	27,355	17,230	17,690	19,182	24,099	26,897	27,896	24,904	26,042
Tarwin	18	14	12	12	2	6	6	9	15
Wa De Lock	12,095	9,403	8,059	10,509	7,194	9,517	10,386	4,832	3,767
Wy Yung	2,438	790	1,110	1,895	631	1,024	798	309	347
Yarram	12,205	8,100	11,070	16,009	12,048	13,911	11,778	6,882	6,740

Table 7 Modelled extractions within each GMA and WSPA reporting region

	Depth upper (m)	Depth lower (m)	Licensed pumps	Mine pumps	S&D	Total pumps
Denison WSPA	0	25	183	0	118	301
Giffard GMA	50	200	16	0	152	168
Leongatha GMA	0	basement	27	0	130	157
Moe GMA	25	basement	67	0	249	316
Orbost GMA	20	45	11	0	13	24
Rosedale GMA Zone 1	50	150	20	48	19	87
Rosedale GMA Zone 2	25	350	229	0	506	735
Rosedale GMA Zone 3	200	350	15	0	11	26
Sale WSPA	25	200	413	0	1011	1424
Stratford GMA Zone 1	150	basement	1	8	7	16
Stratford GMA Zone 2	350	basement	5	0	15	24
Tarwin GMA	0	25	1	0	23	24
WaDeLock GMA	0	25	301	0	323	627
Wy Yung WSPA	0	25	110	0	71	181
Yarram WSPA Zone 1	0	basement	102	0	510	612
Yarram WSPA Zone 2	200	basement	6	0	17	23

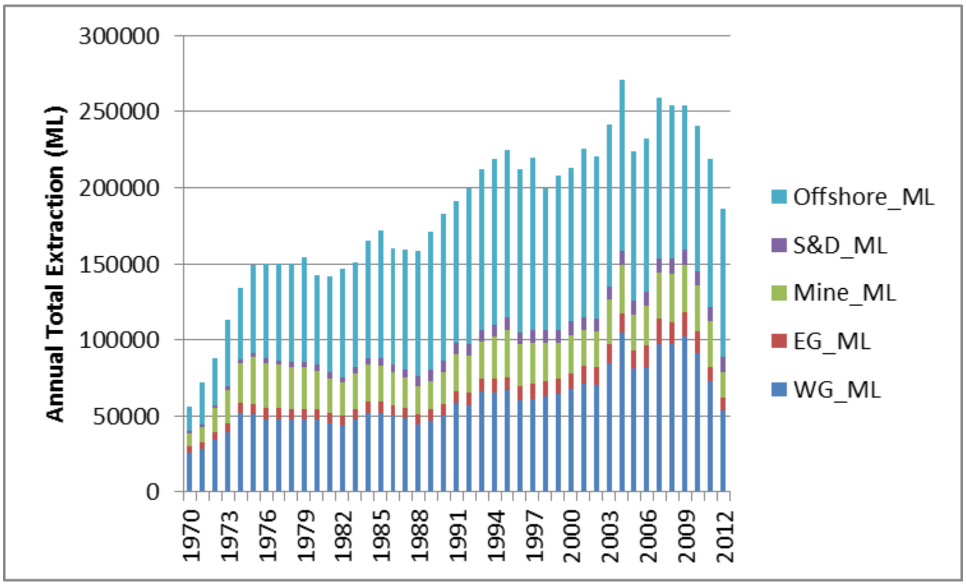


Figure 43 **Modelled 1970 to 2012 annual total extraction (ML/yr) by contribution. S&D refers to stock and domestic usage, Mine refers to mine dewatering, EG refers to east Gippsland usage and WG refers to West Gippsland usage**

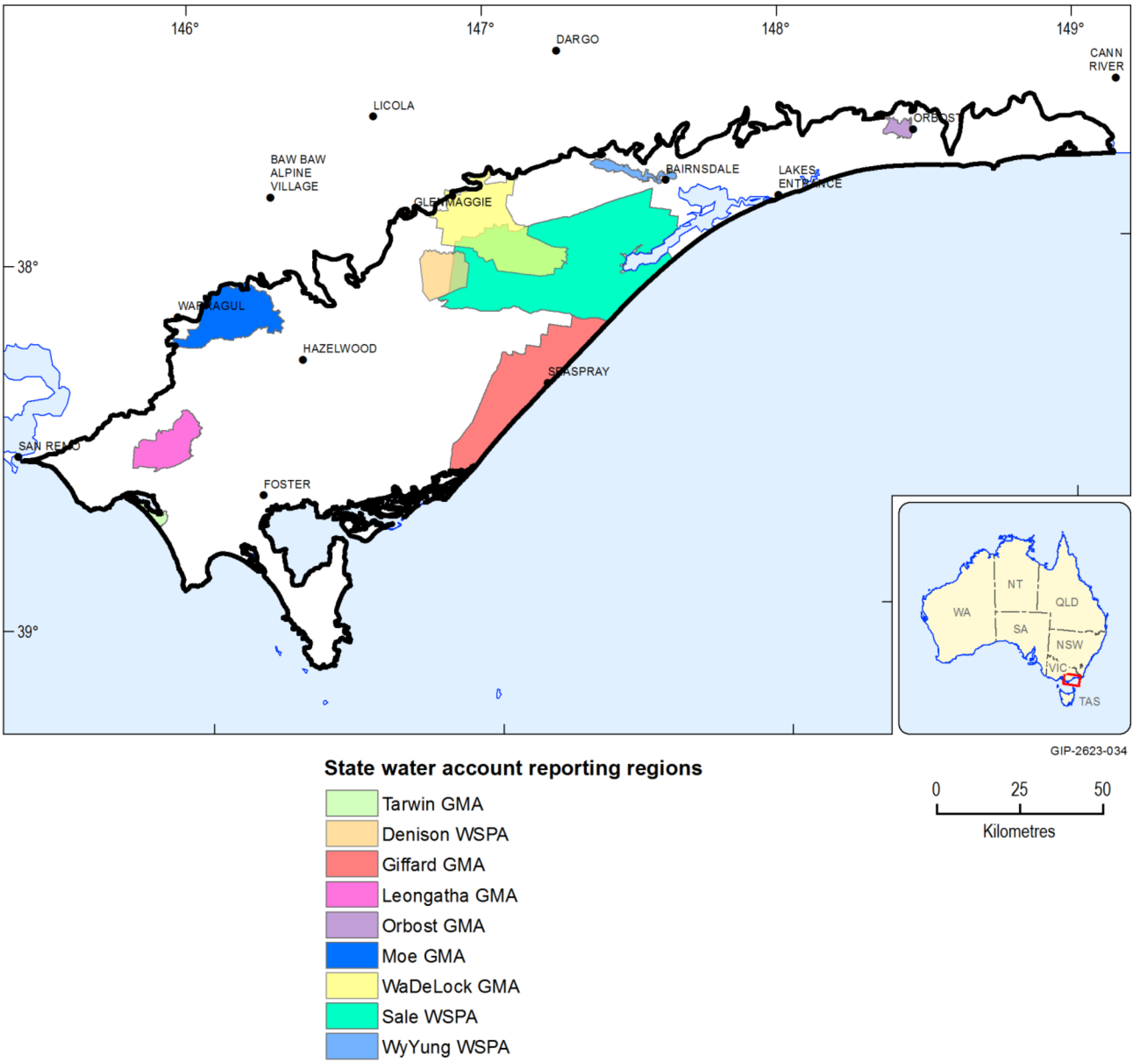


Figure 44 State water account reporting regions (excluding Rosedale, Stratford and Yarram)

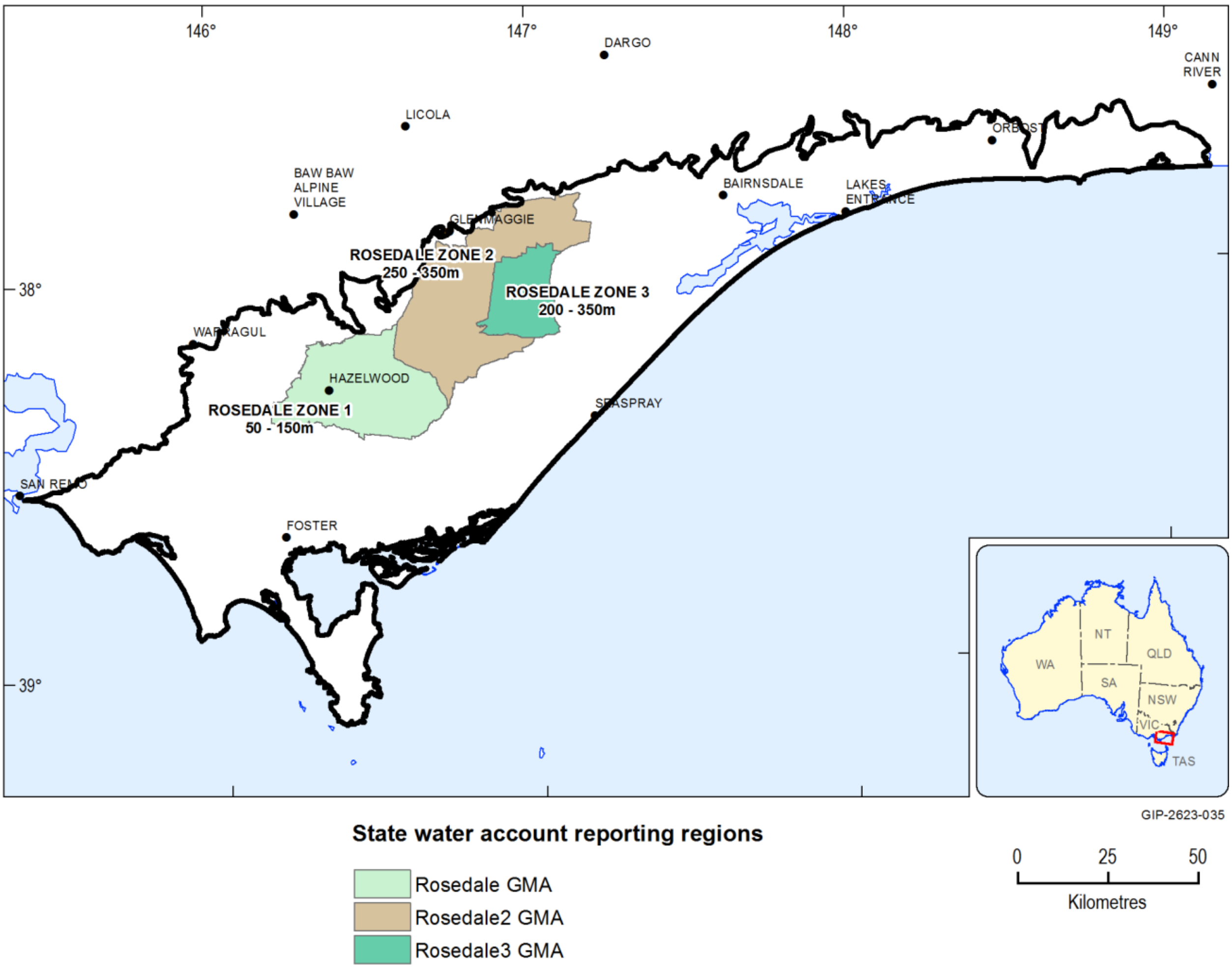


Figure 45 Rosedale water account reporting regions (and associated depths)

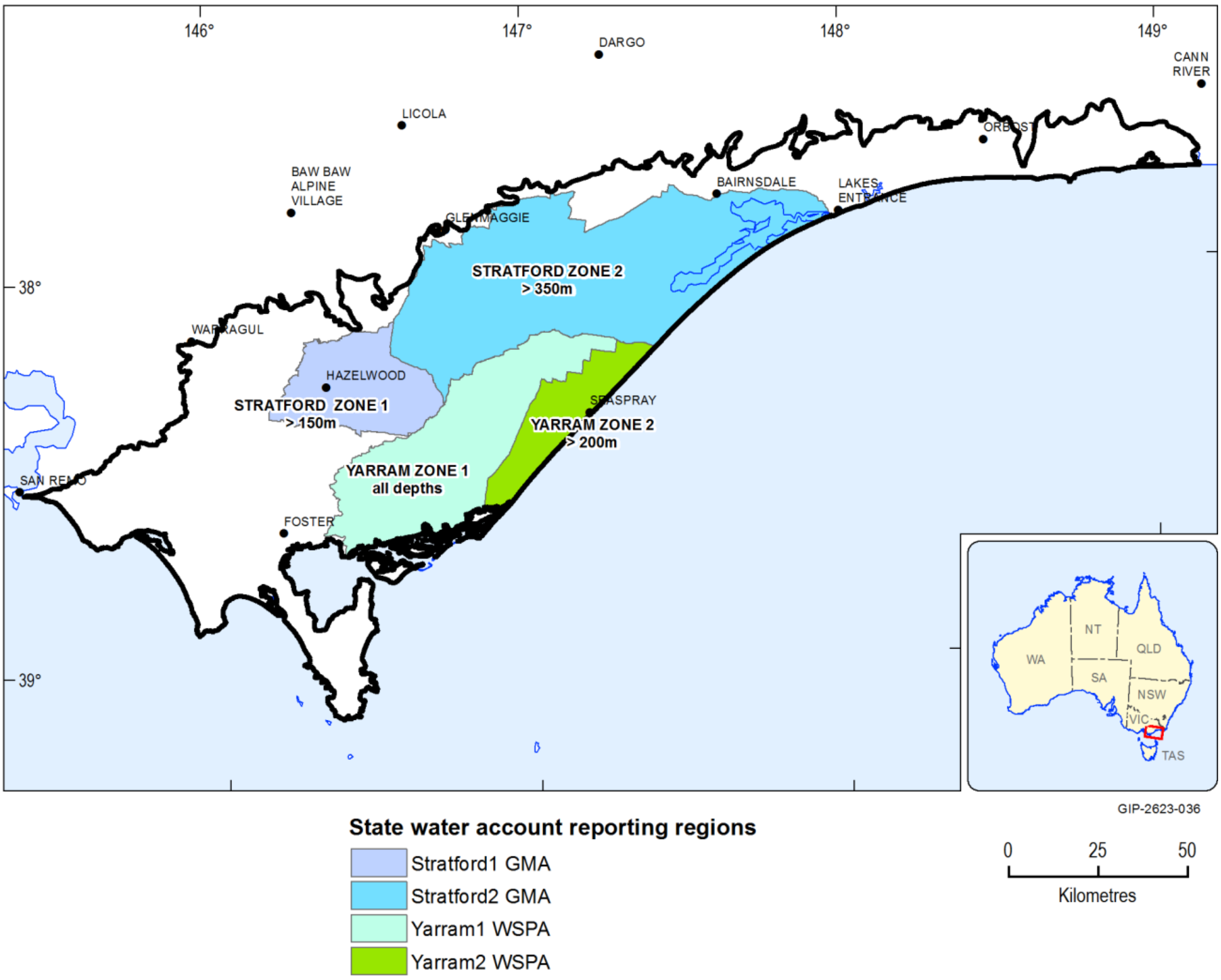


Figure 46 Stratford and Yarram water account reporting regions (and associated depths)

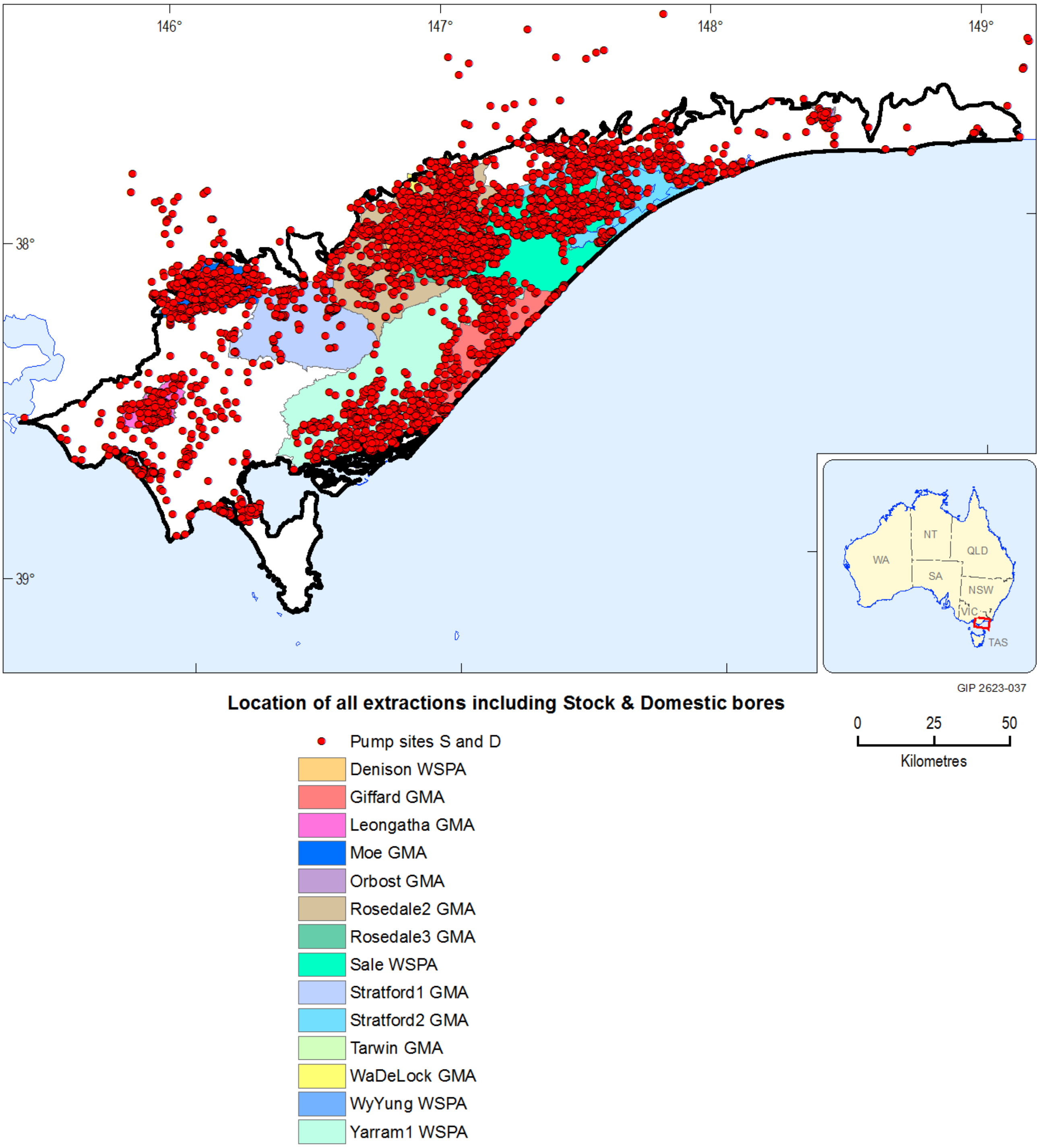


Figure 47 Location of all modelled groundwater extraction bores (including stock and domestic bores)

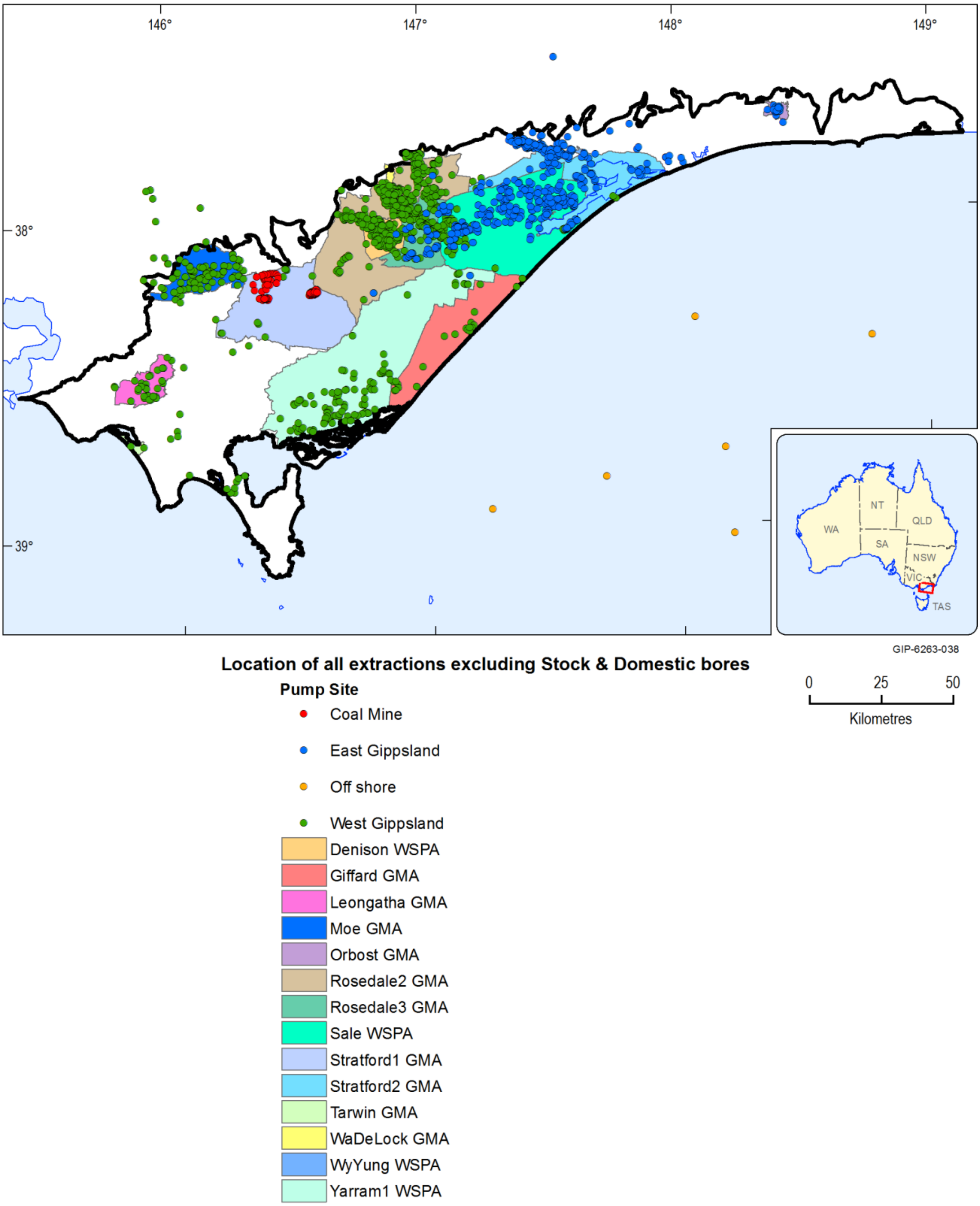


Figure 48 Location of modelled offshore production bores, mine dewatering and groundwater extraction bores (excluding stock and domestic bores)

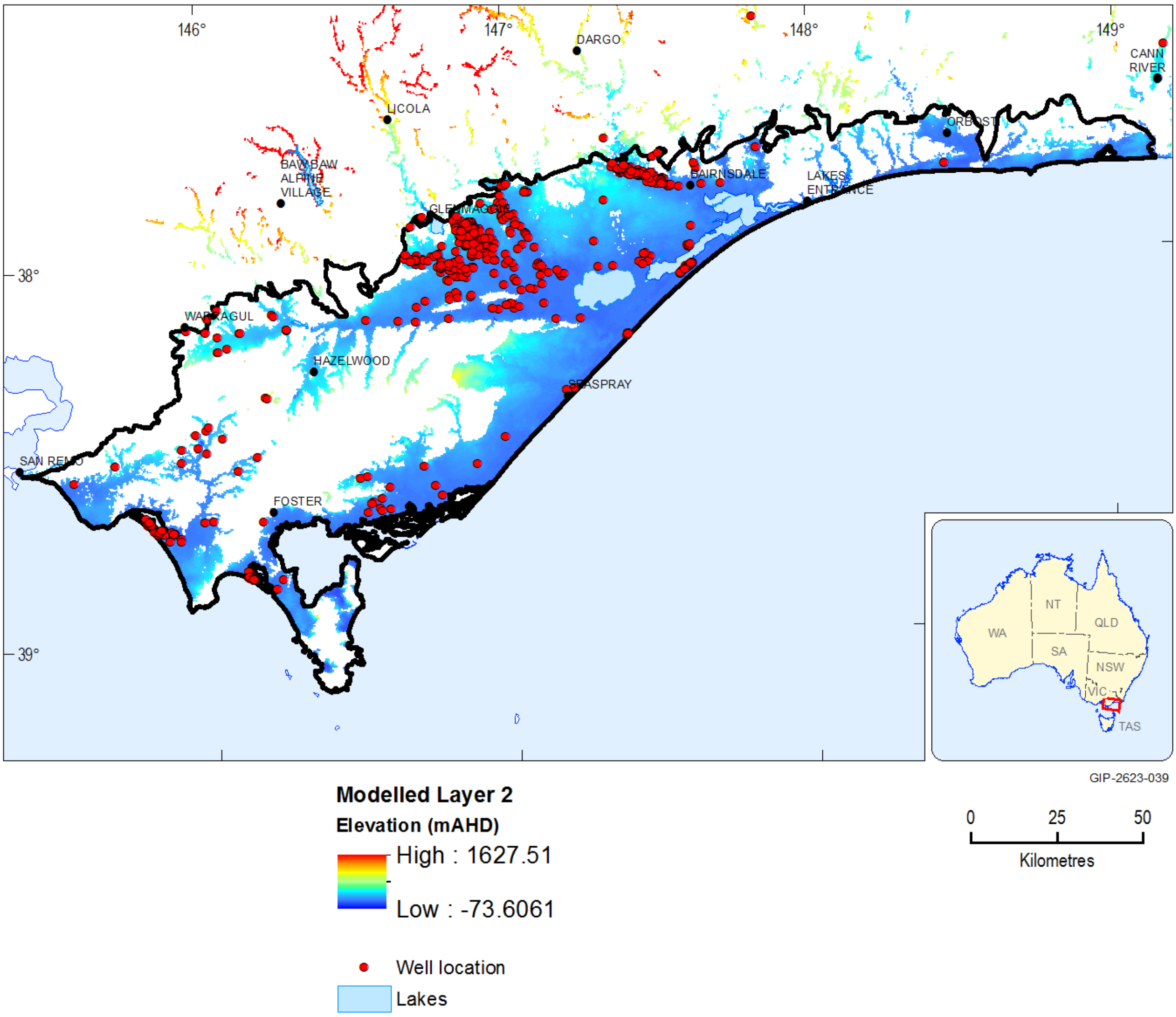


Figure 49 Location of extraction bores in modelled layer 2

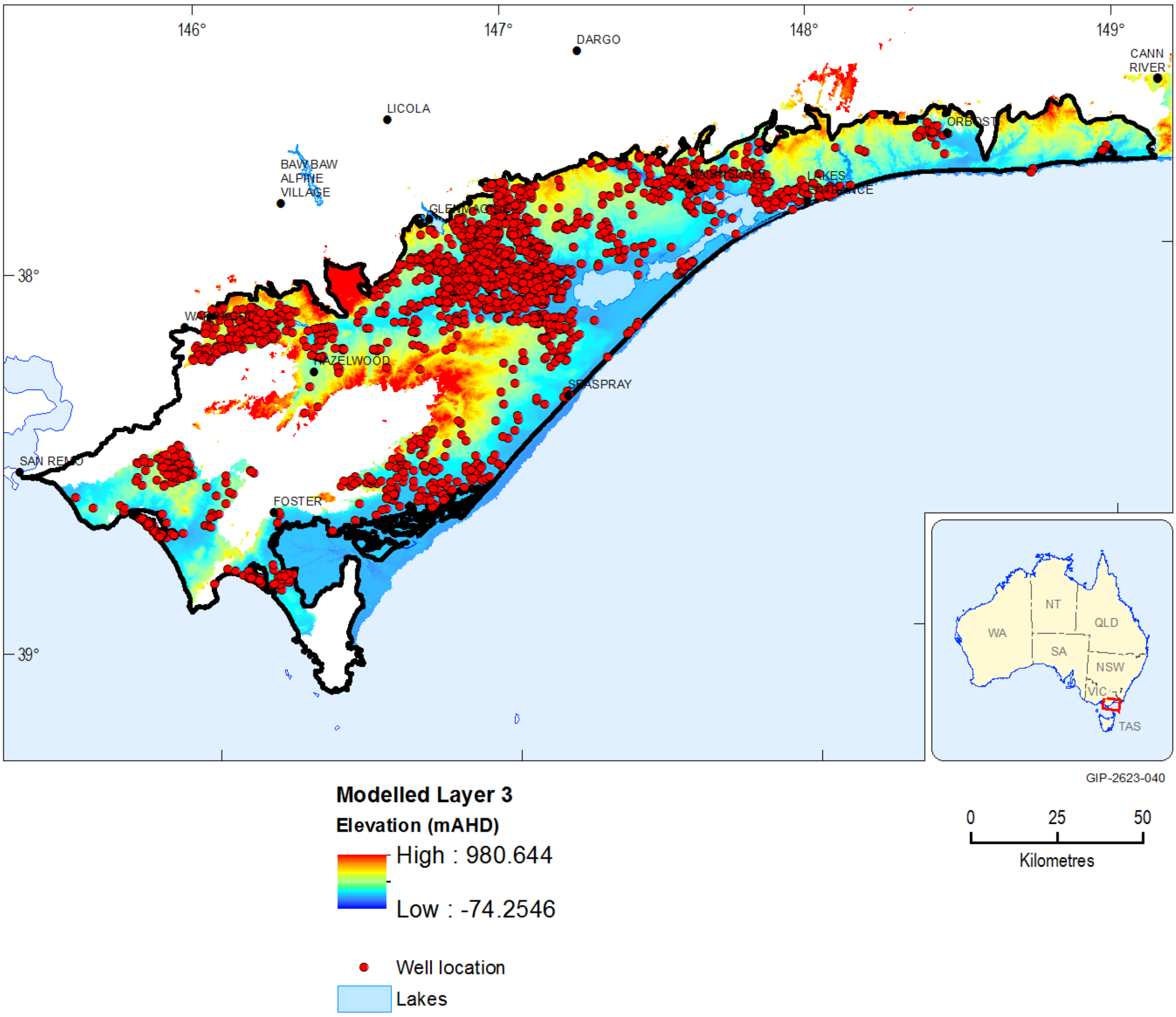


Figure 50 Location of extraction bores in modelled layer 3

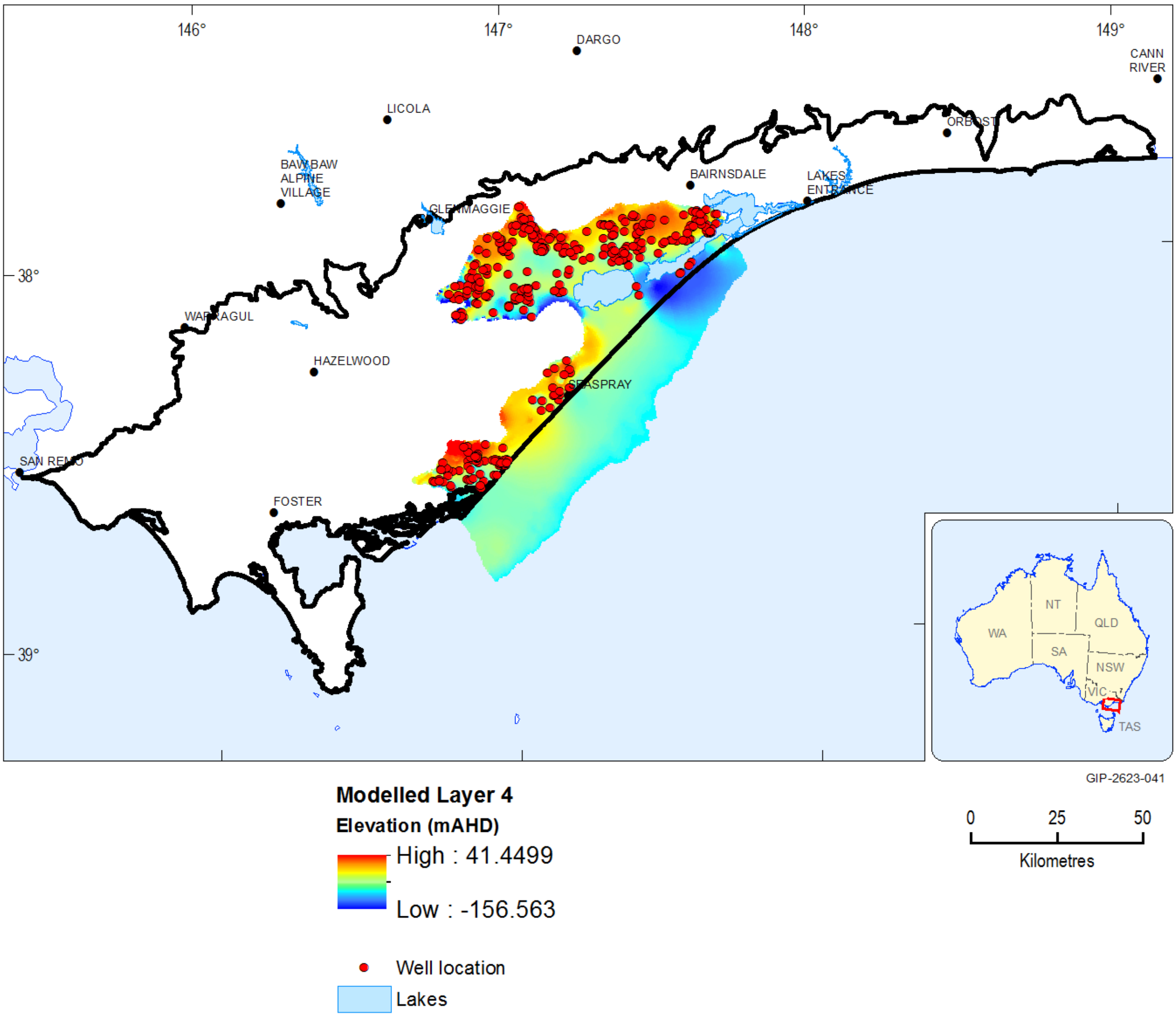


Figure 51 **Location of extraction bores in modelled layer 4**

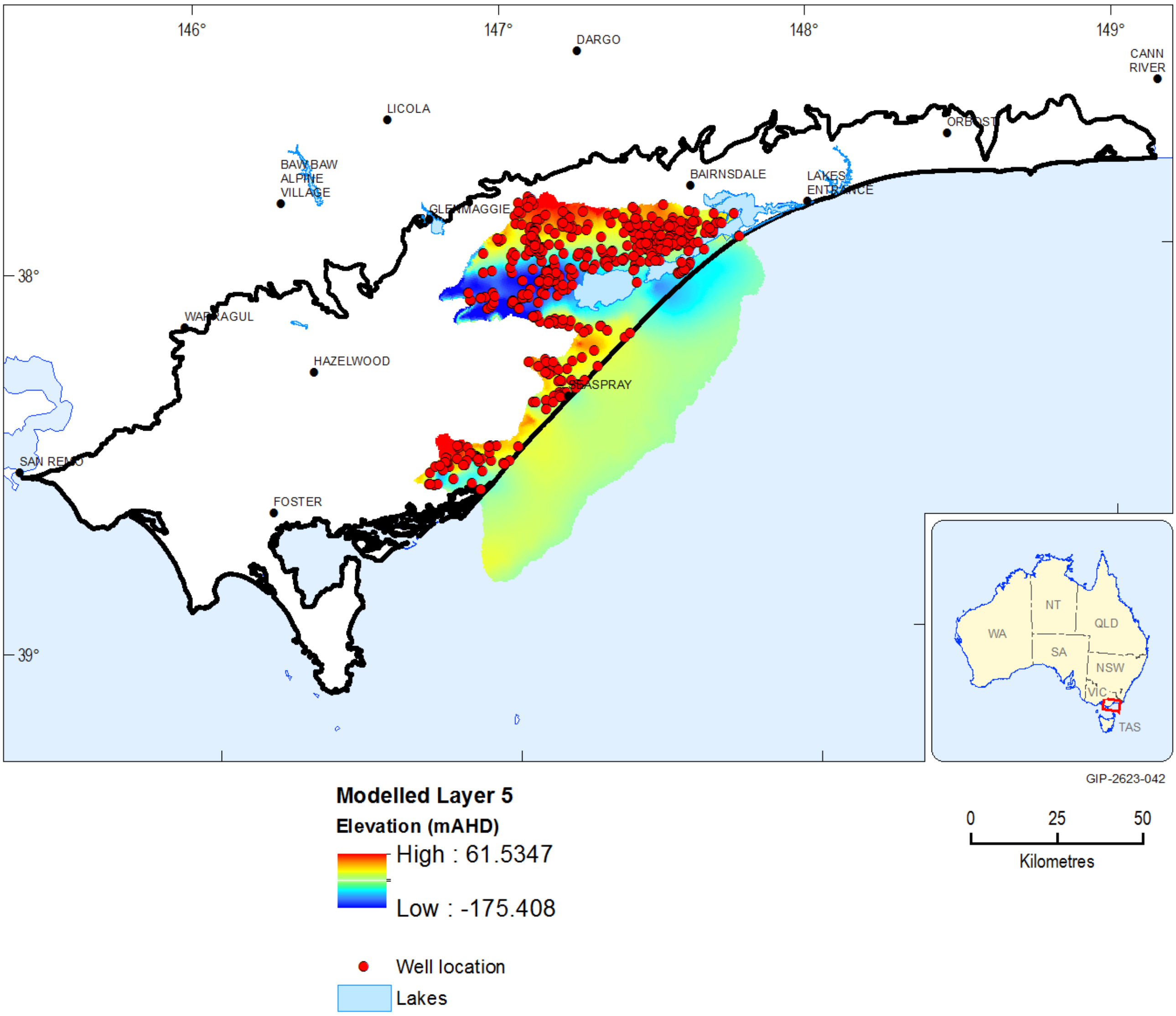


Figure 52 Location of extraction bores in modelled layer 5

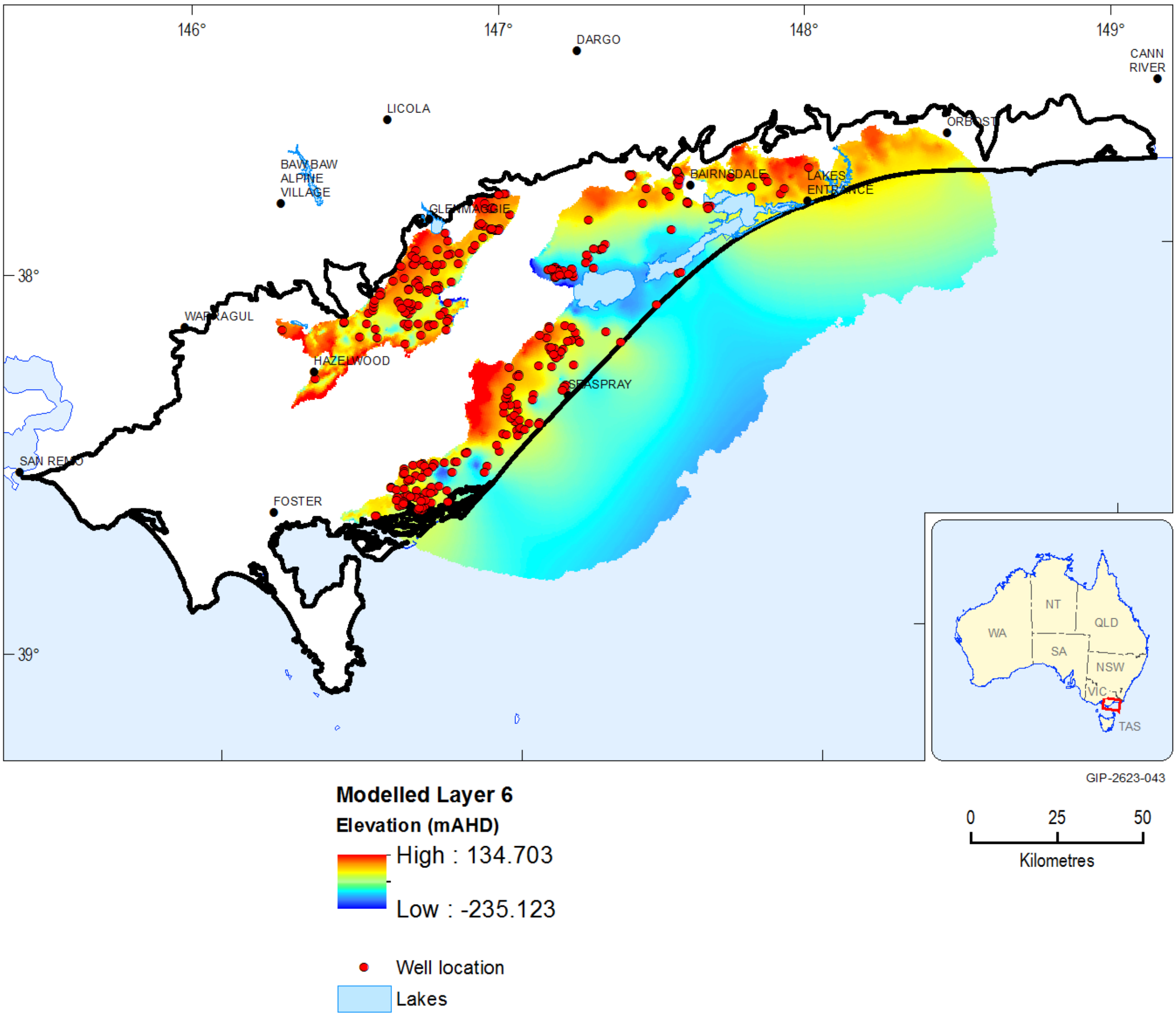


Figure 53 Location of extraction bores in modelled layer 6

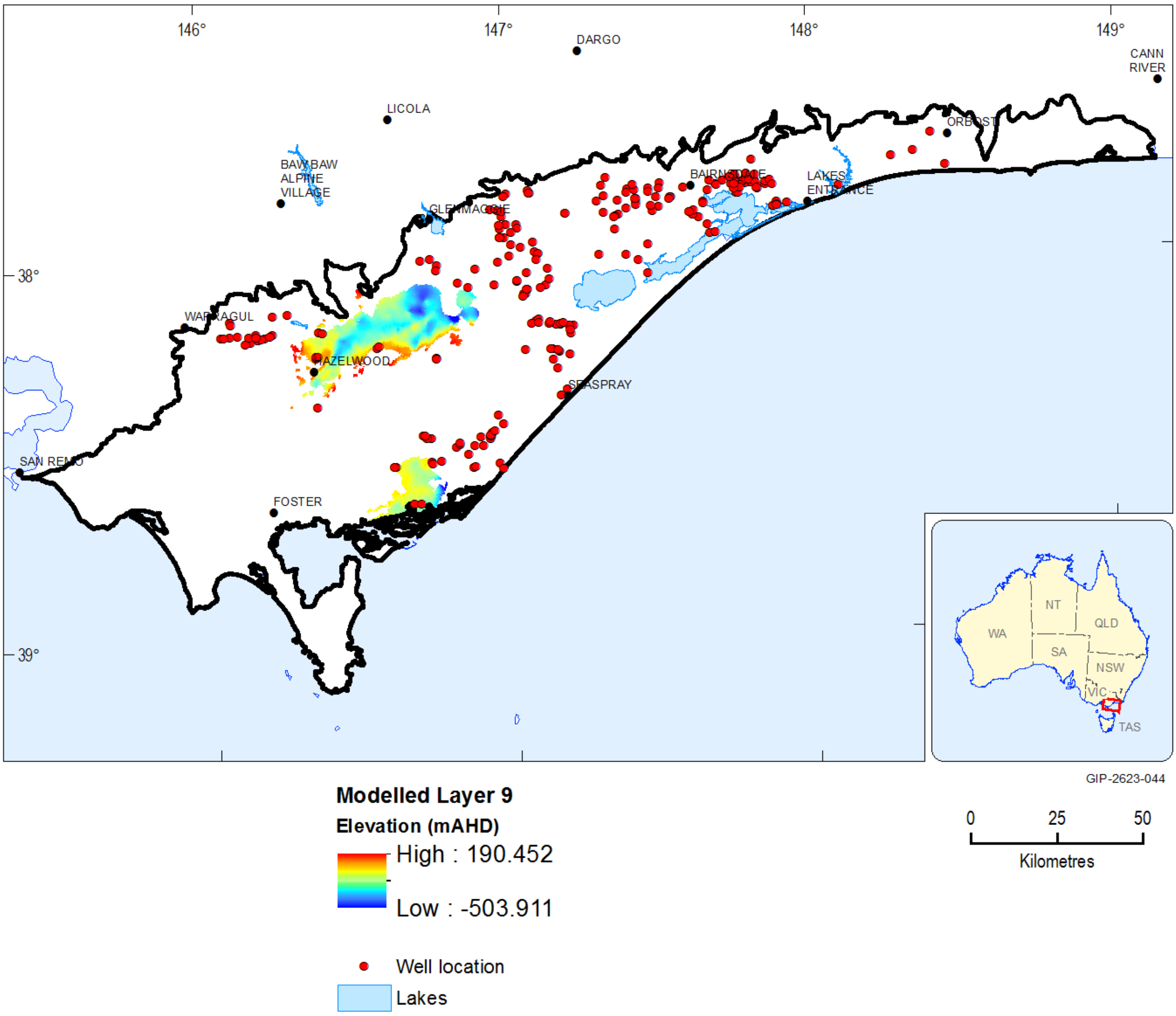


Figure 54 Location of extraction bores in modelled layer 9

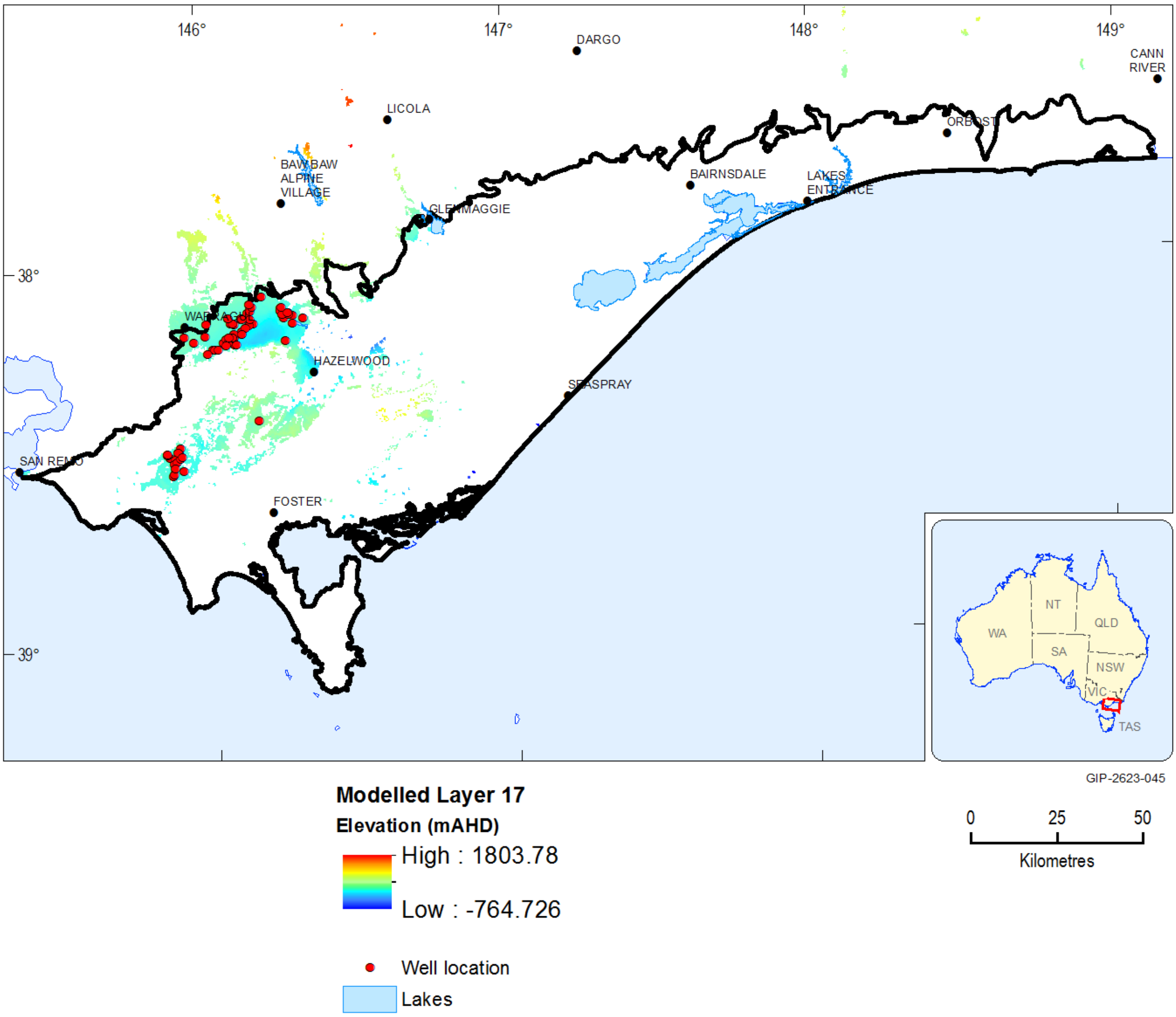


Figure 55 Location of extraction bores in modelled layer 17

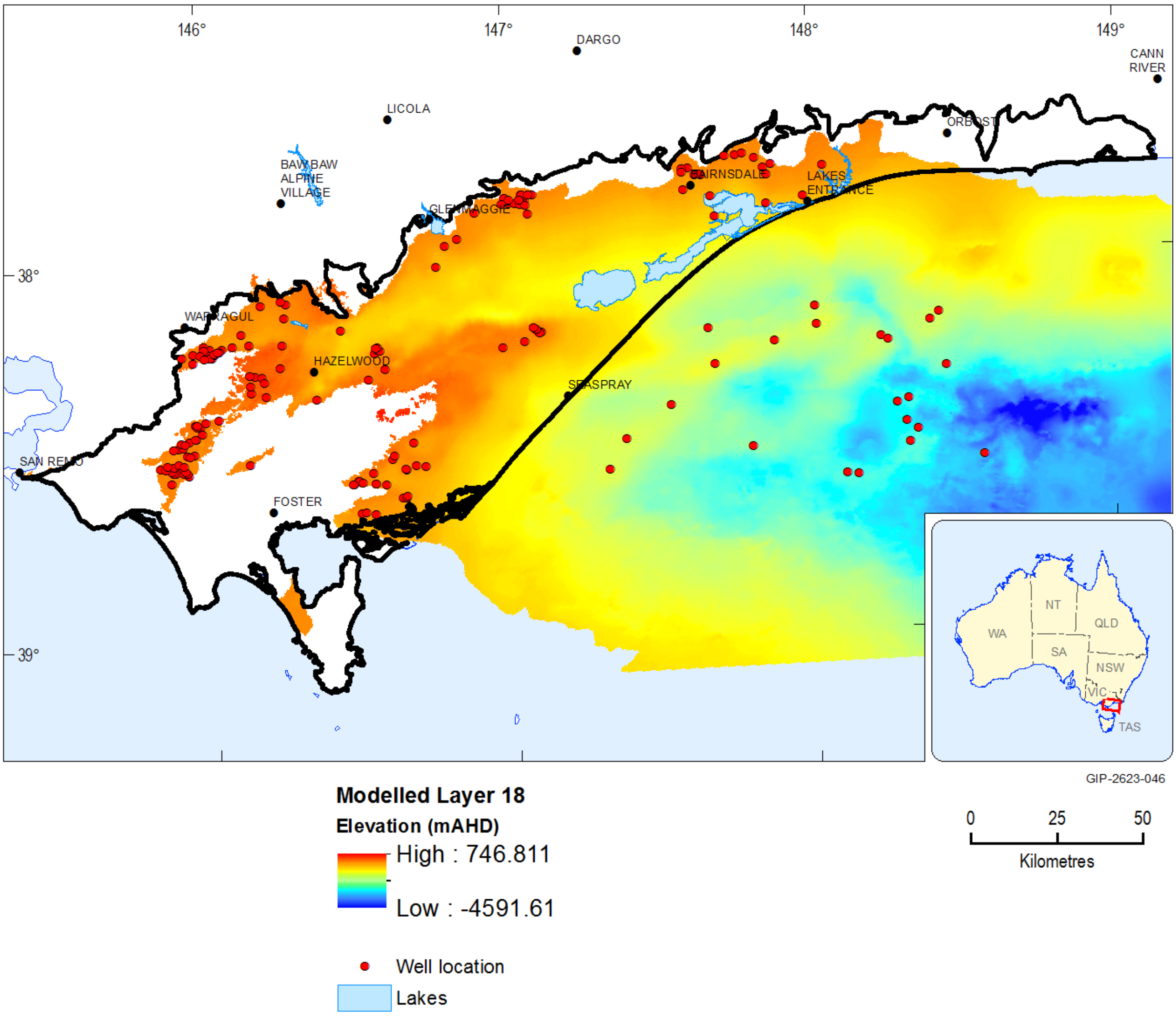


Figure 56 Location of extraction bores in modelled layer 18

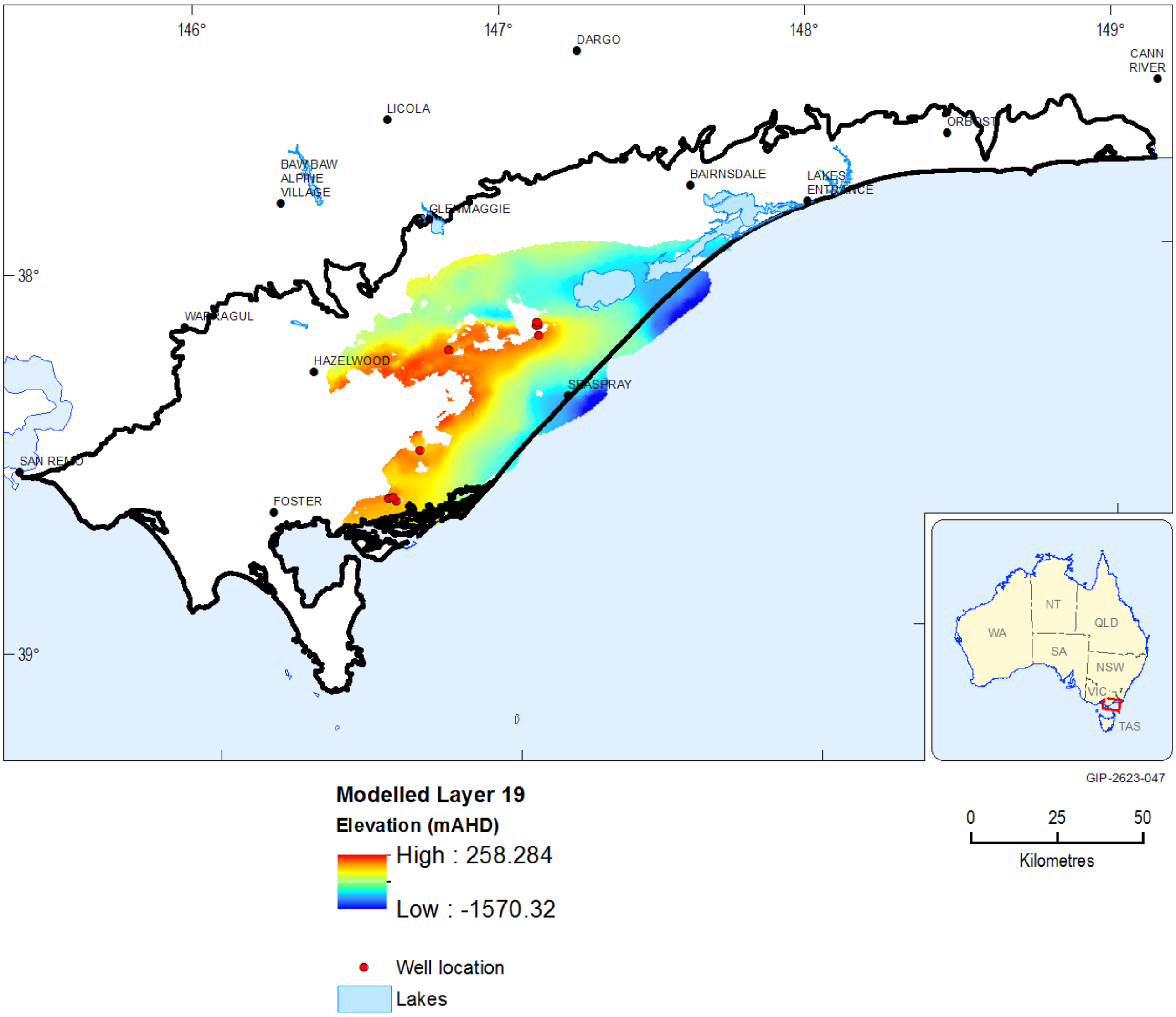


Figure 57 Location of extraction bores in modelled layer 19

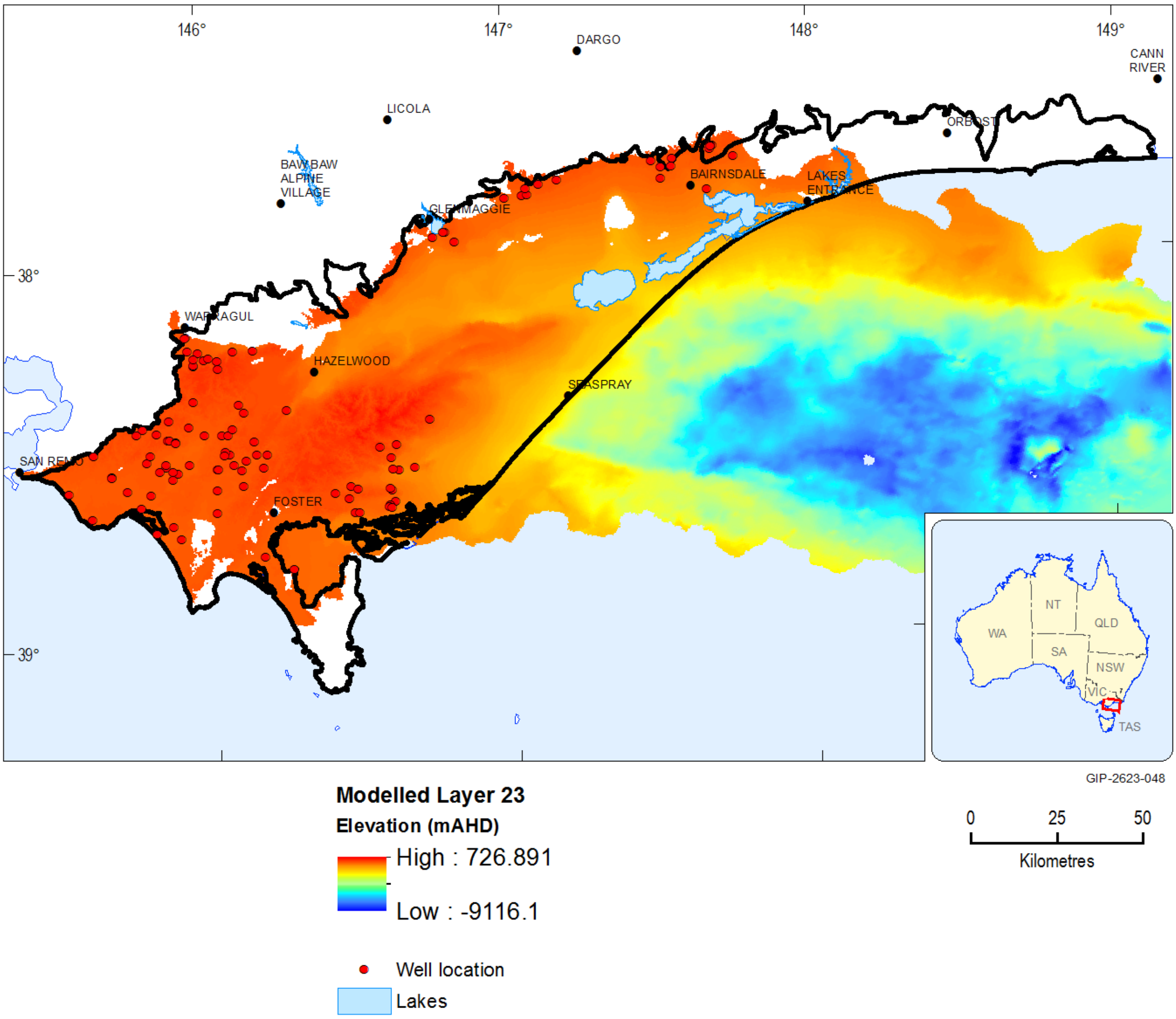


Figure 58 Location of extraction bores in modelled layer 23

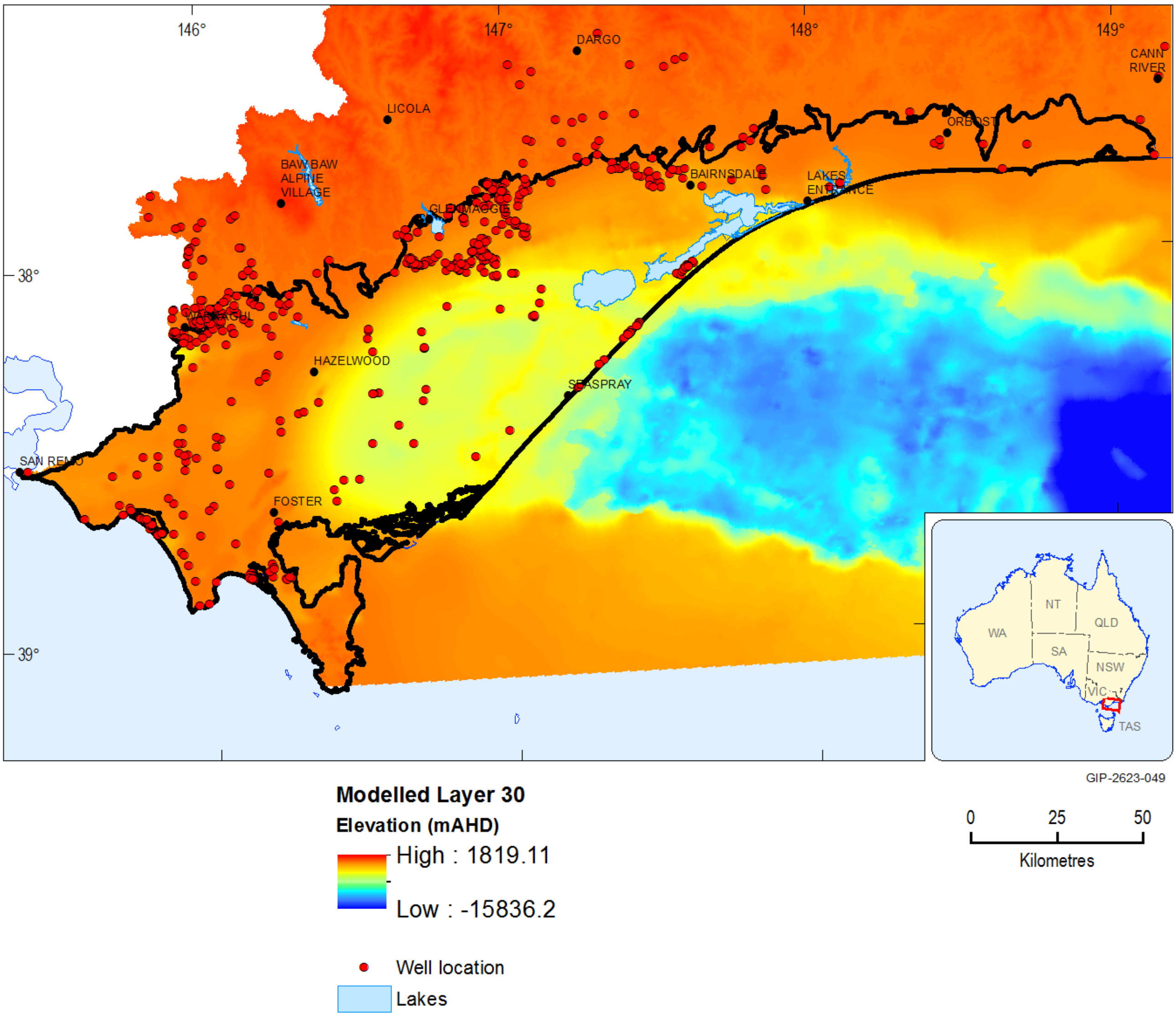


Figure 59 Location of extraction bores in modelled layer 30

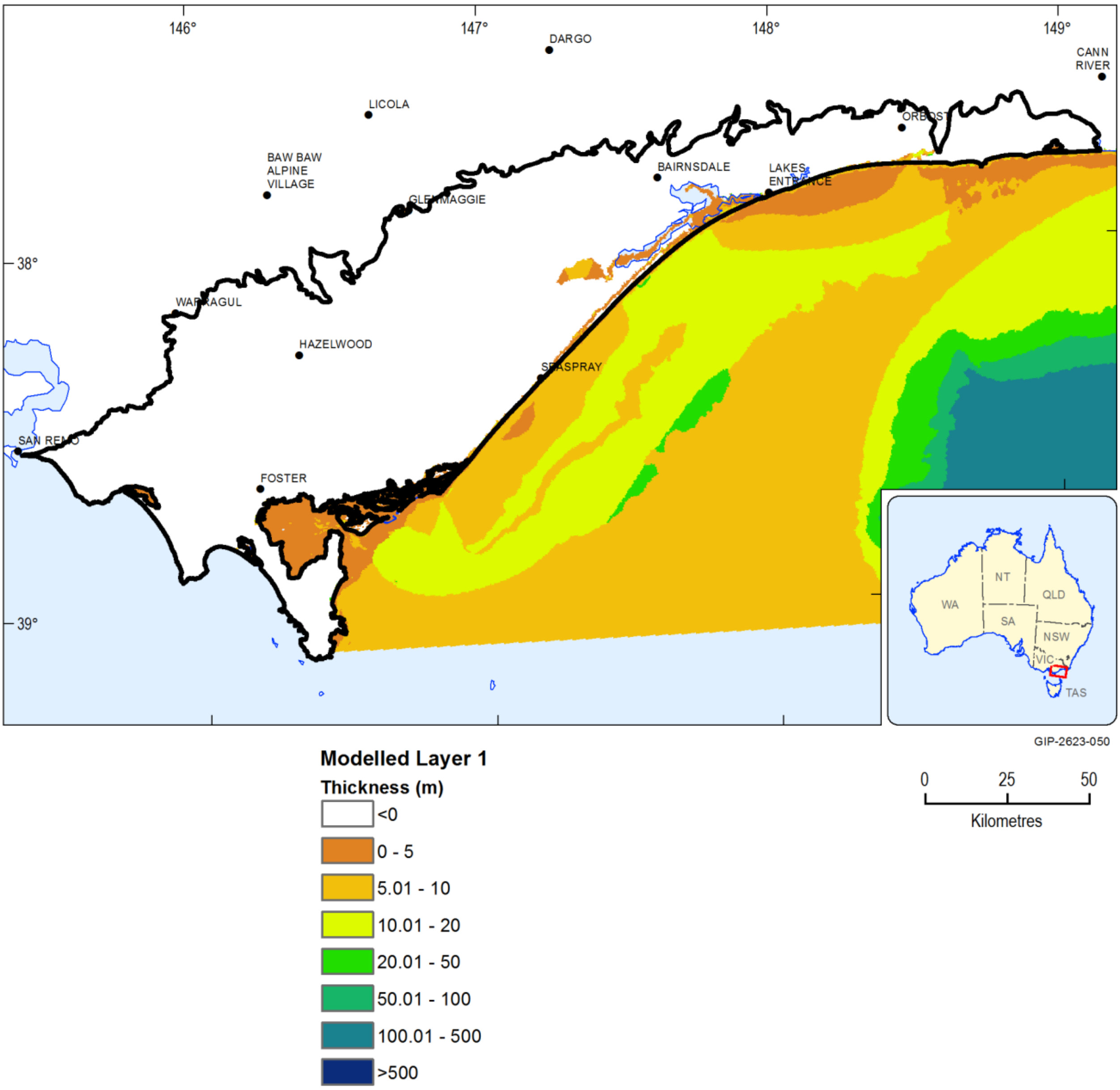


Figure 60 Thickness of modelled layer 1

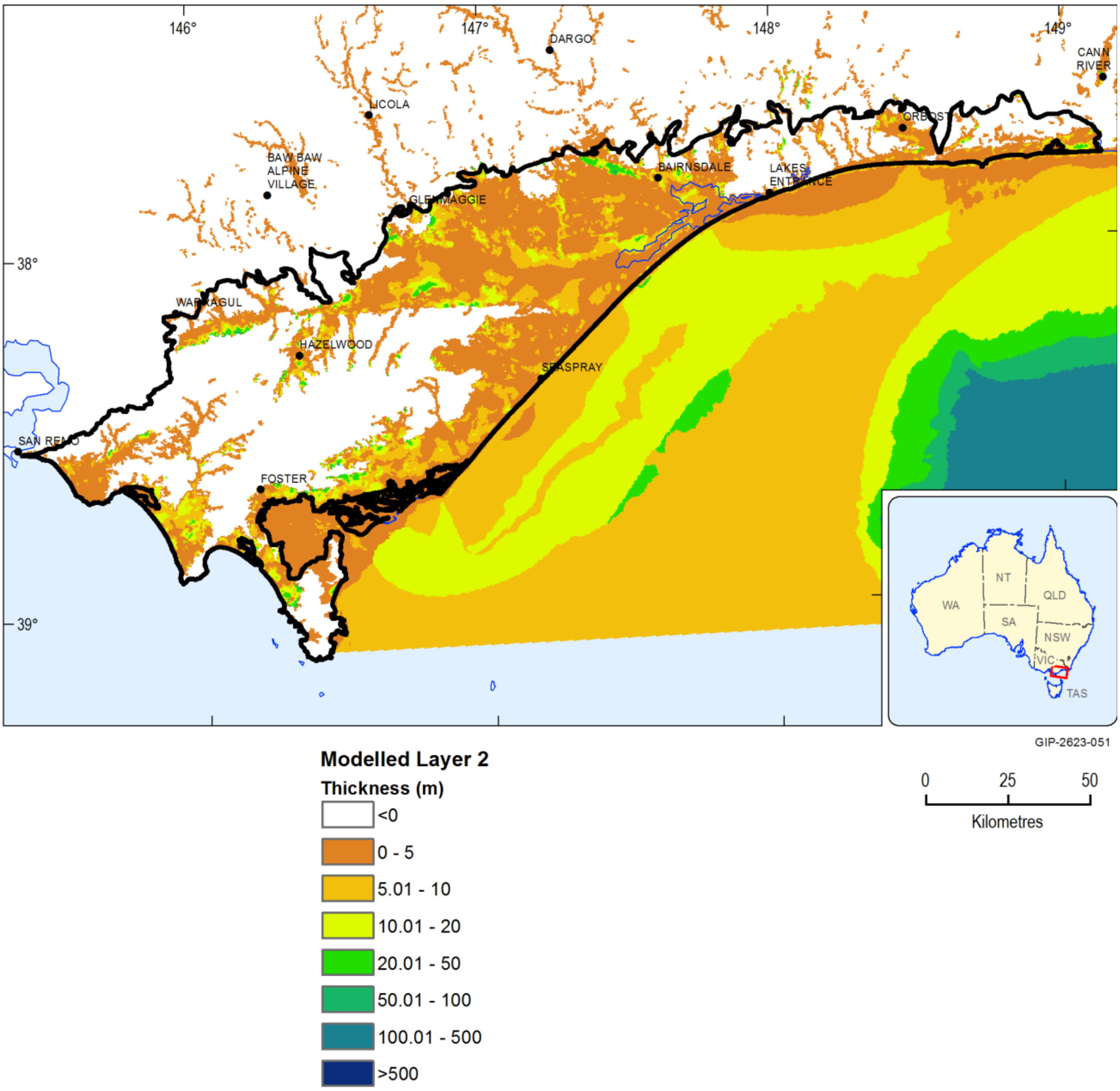


Figure 61 Thickness of modelled layer 2

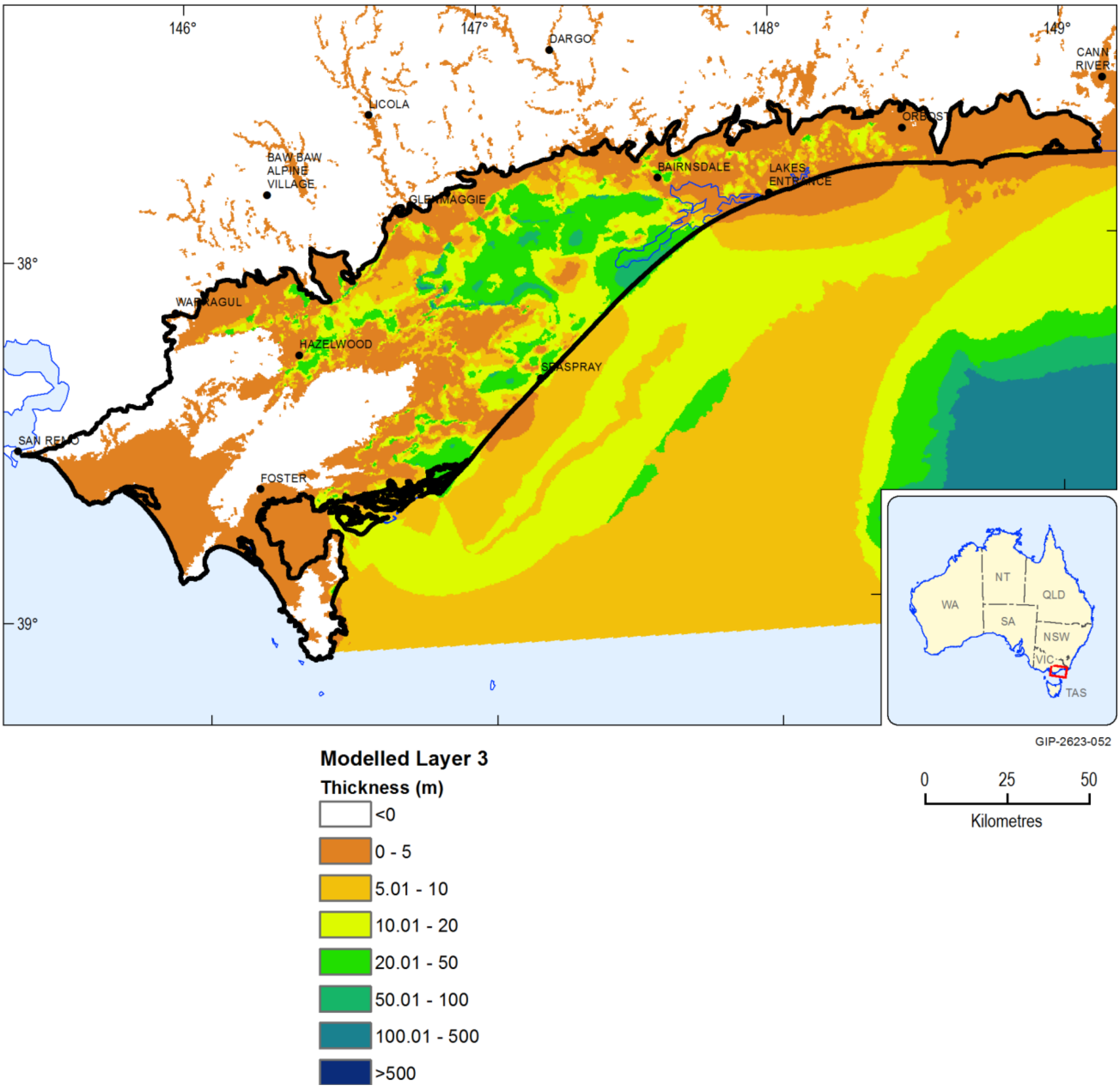


Figure 62 Thickness of modelled layer 3

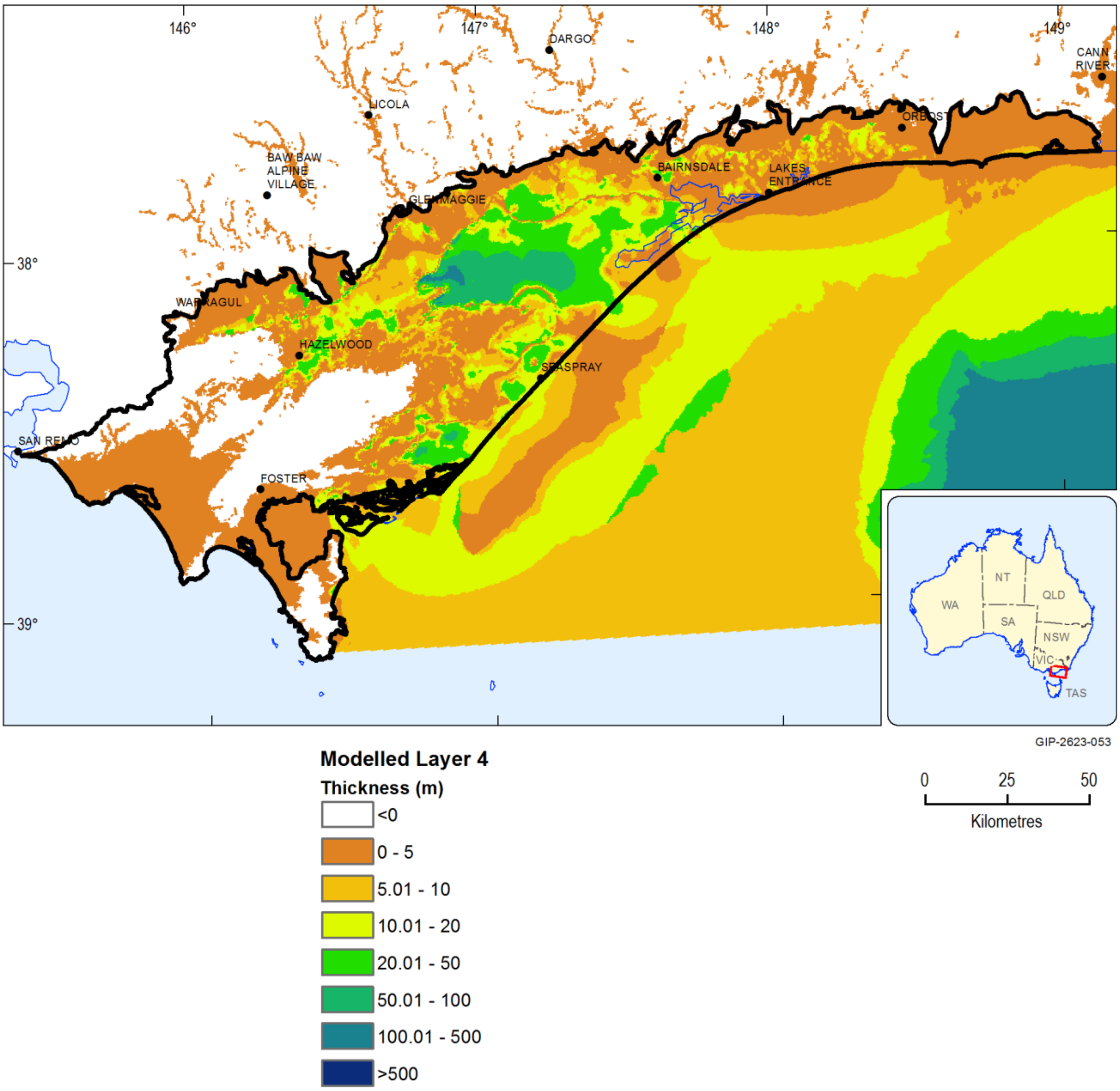


Figure 63 Thickness of modelled layer 4

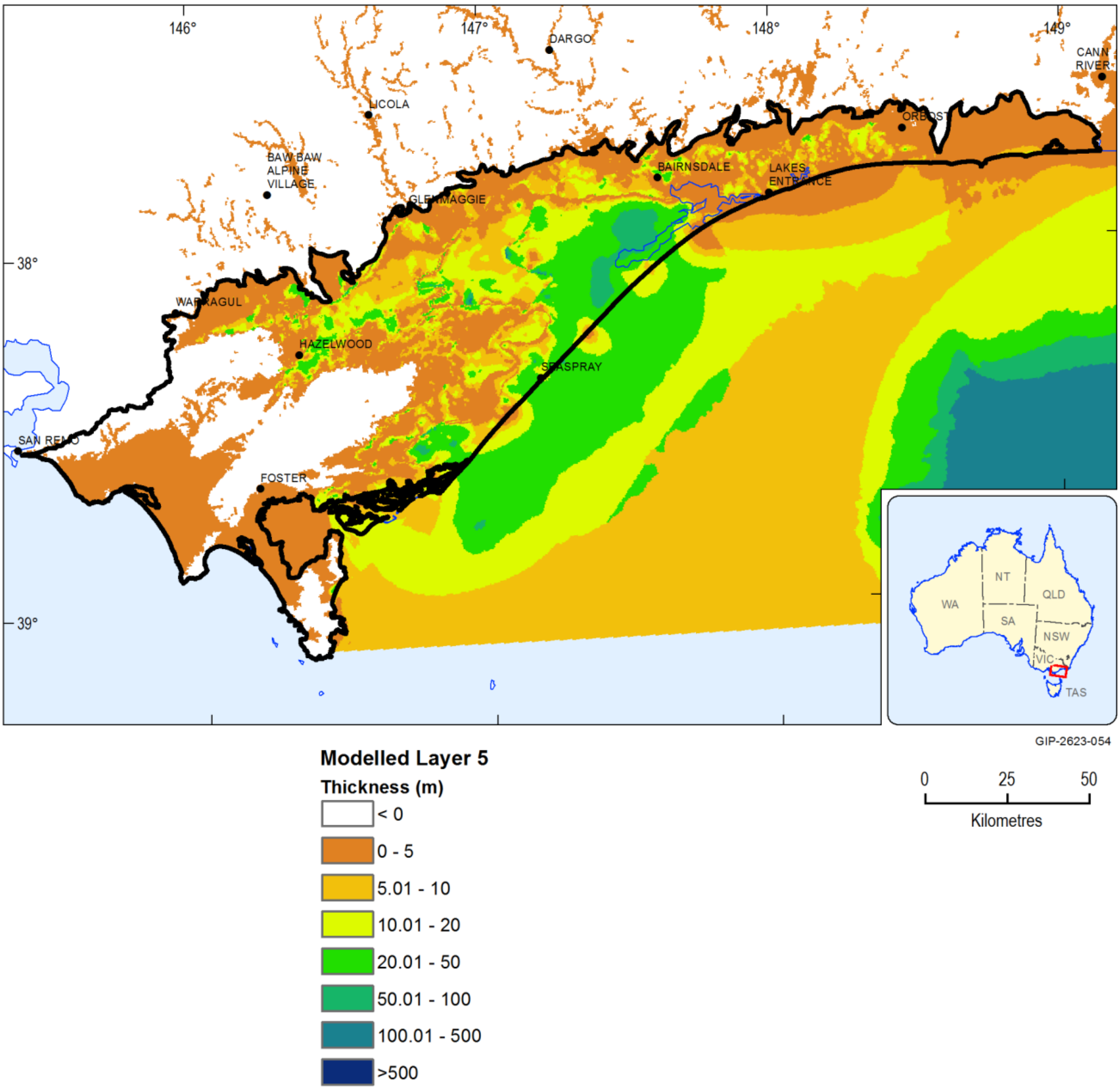


Figure 64 Thickness of modelled layer 5

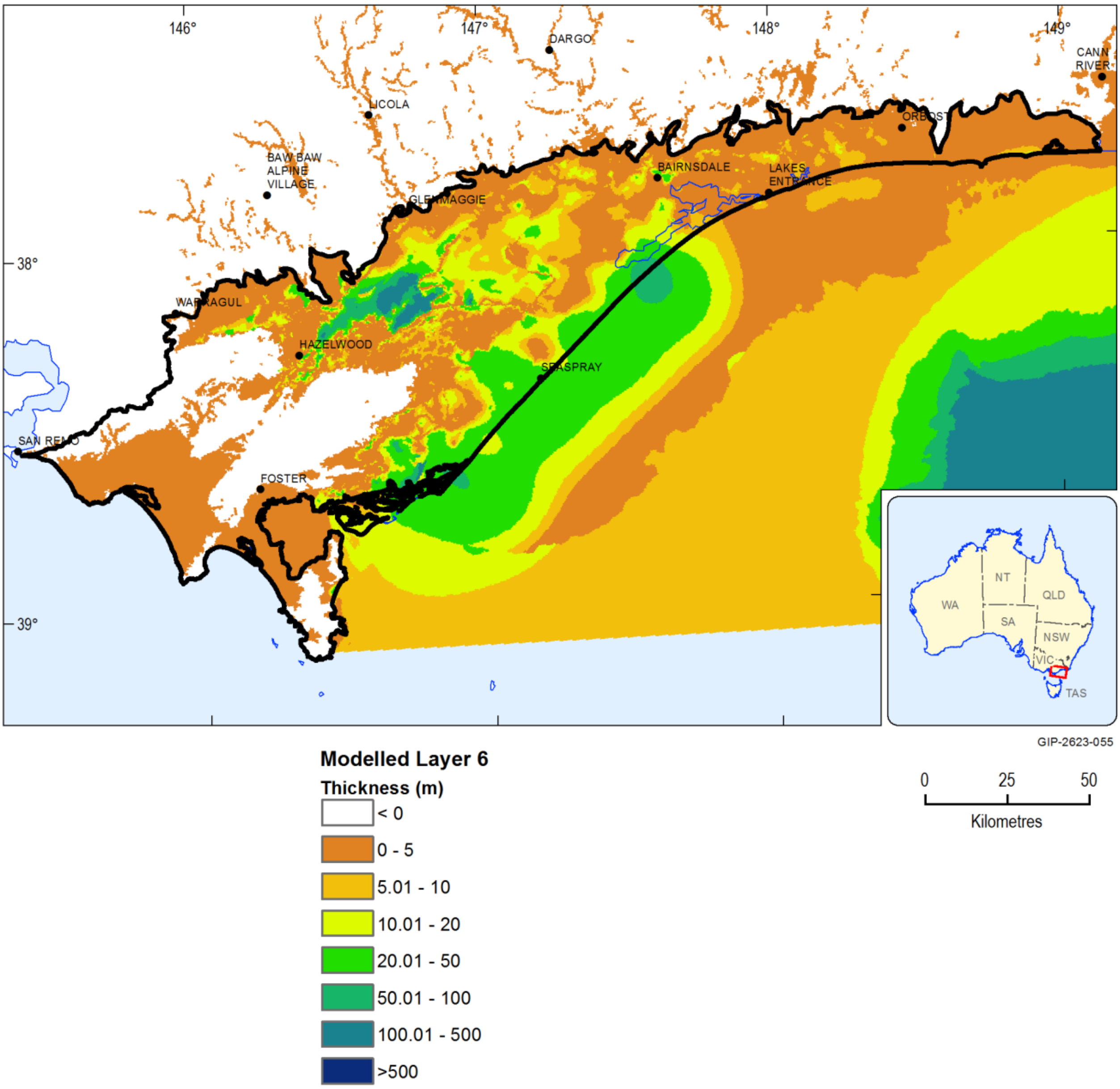


Figure 65 Thickness of modelled layer 6

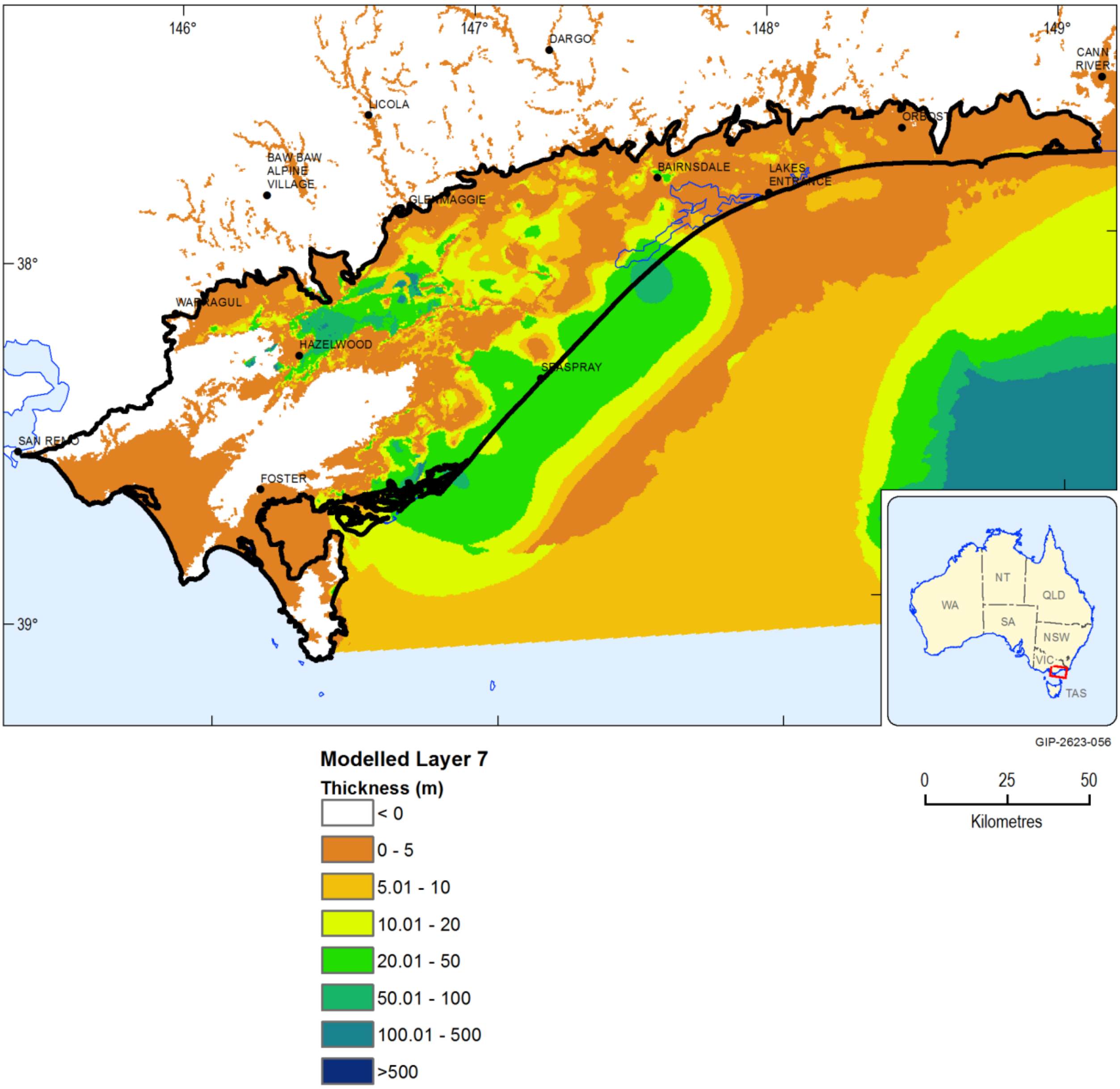


Figure 66 Thickness of modelled layer 7

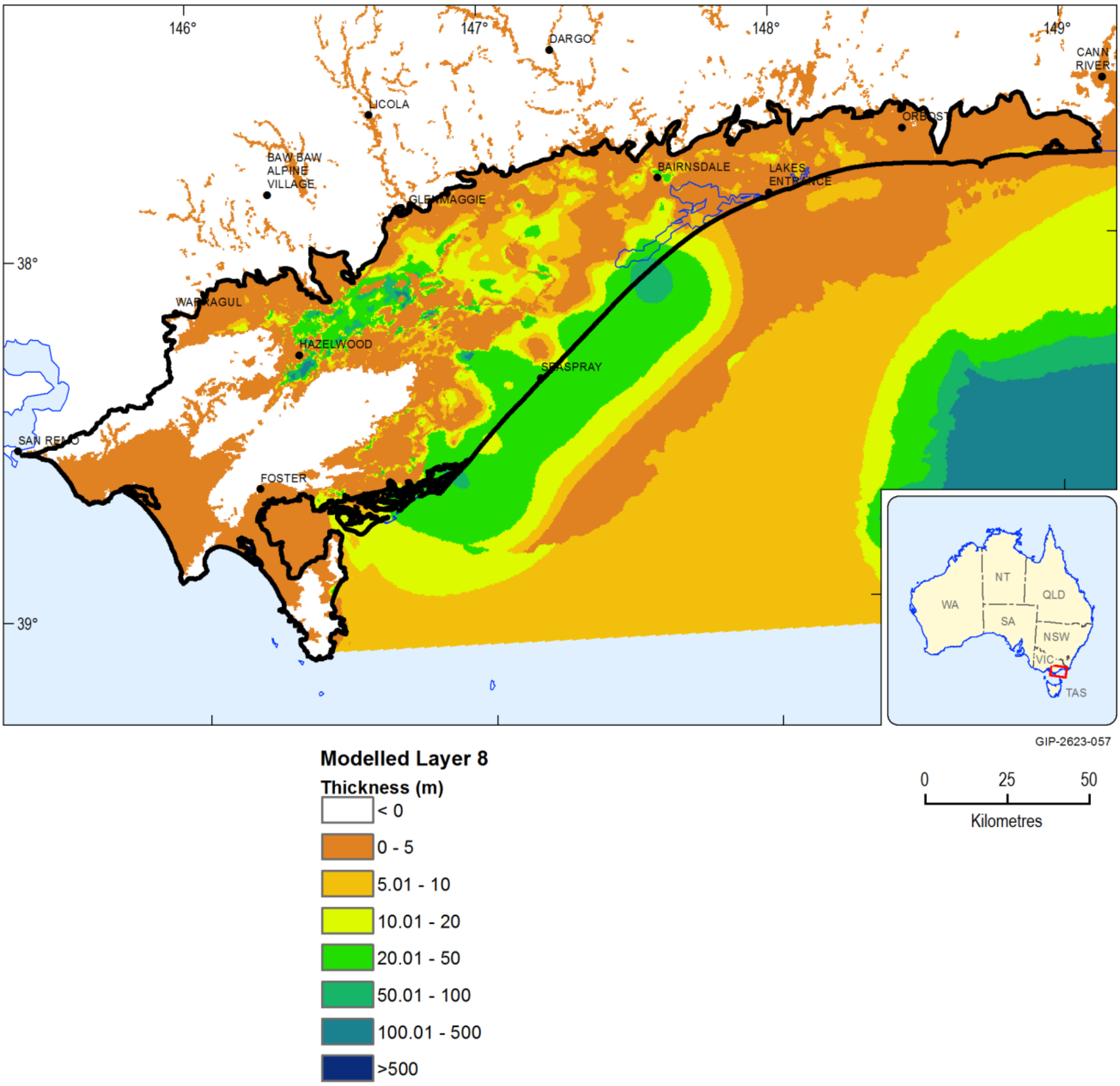


Figure 67 Thickness of modelled layer 8

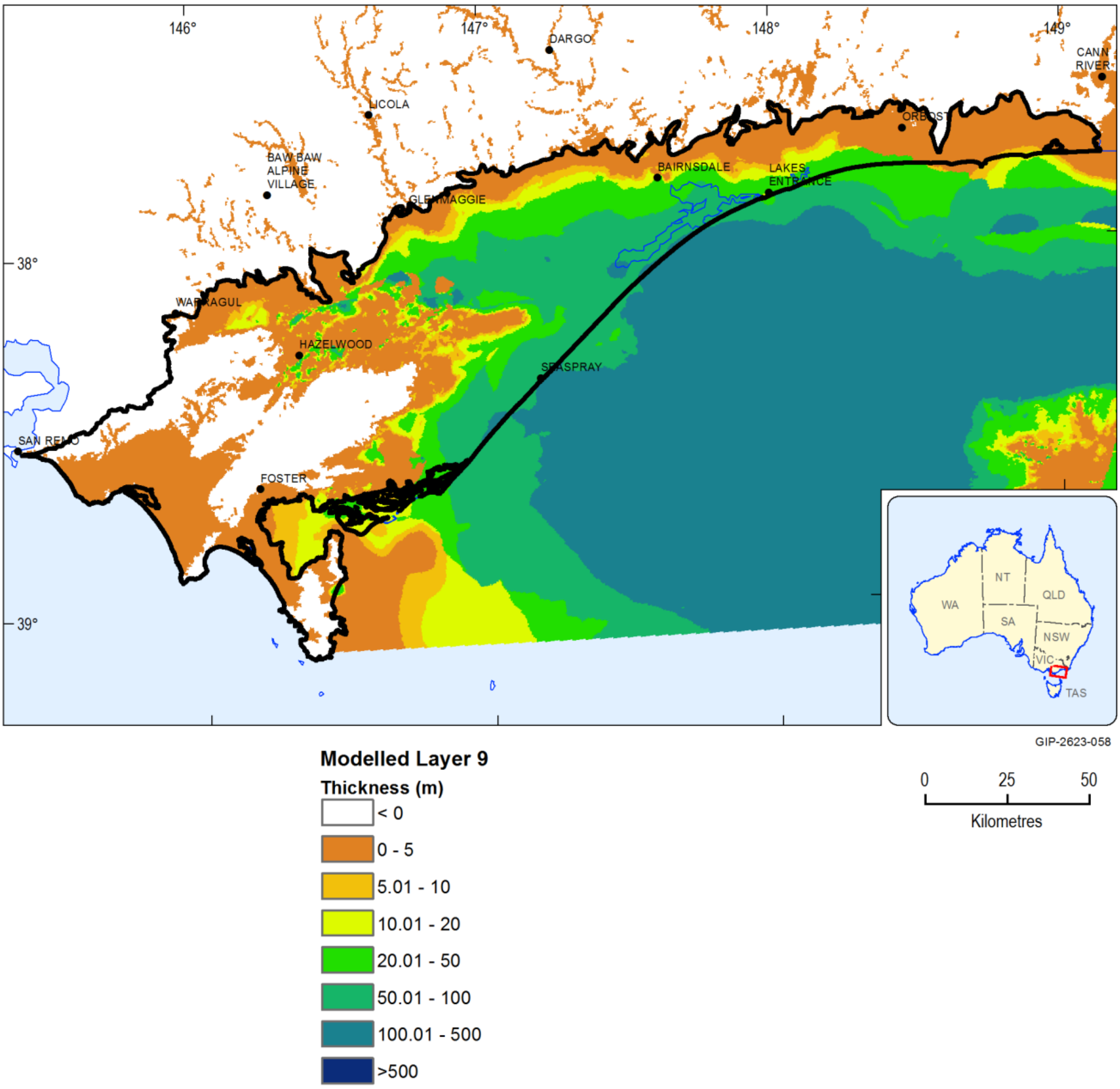


Figure 68 Thickness of modelled layer 9

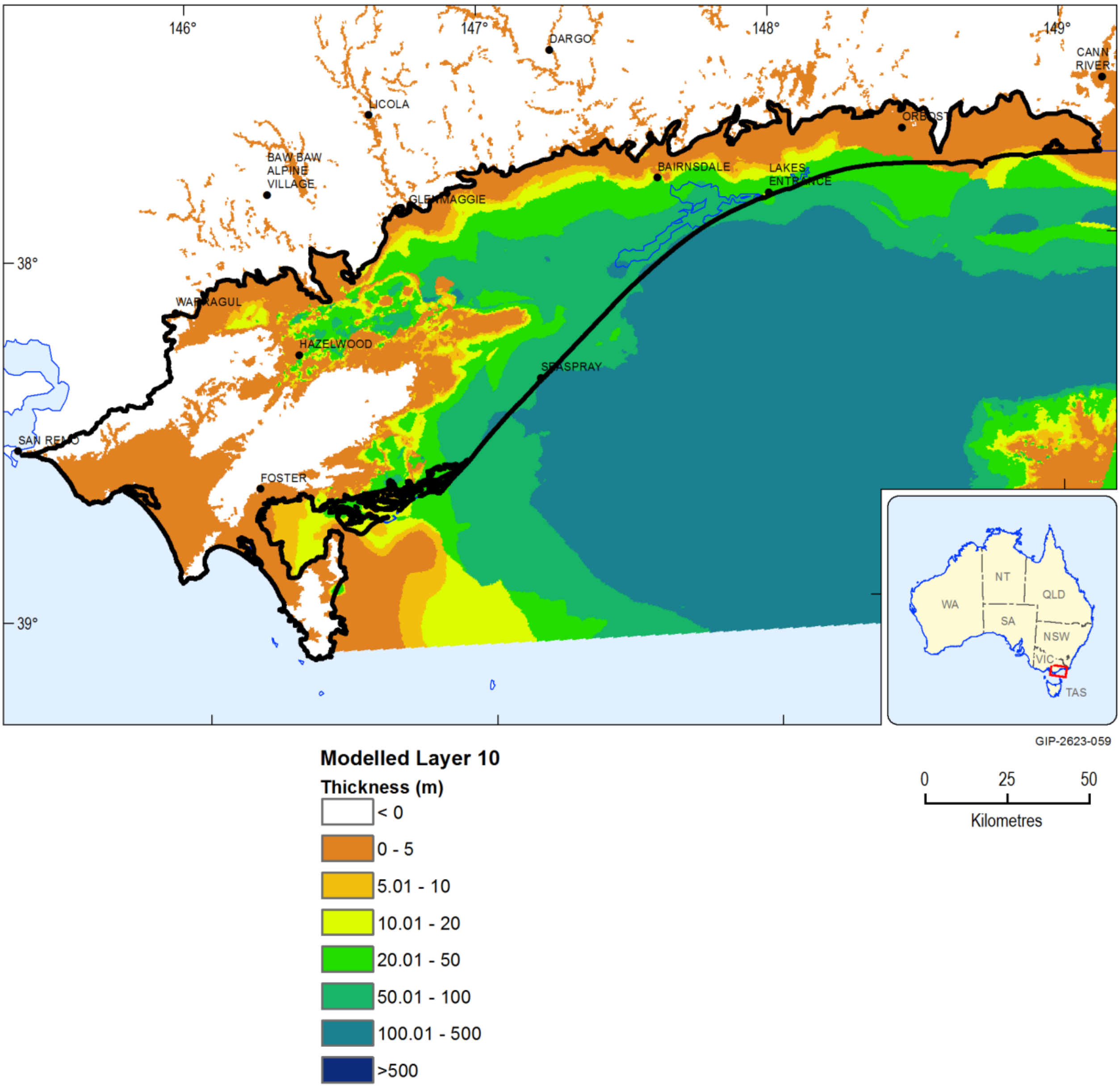


Figure 69 Thickness of modelled layer 10

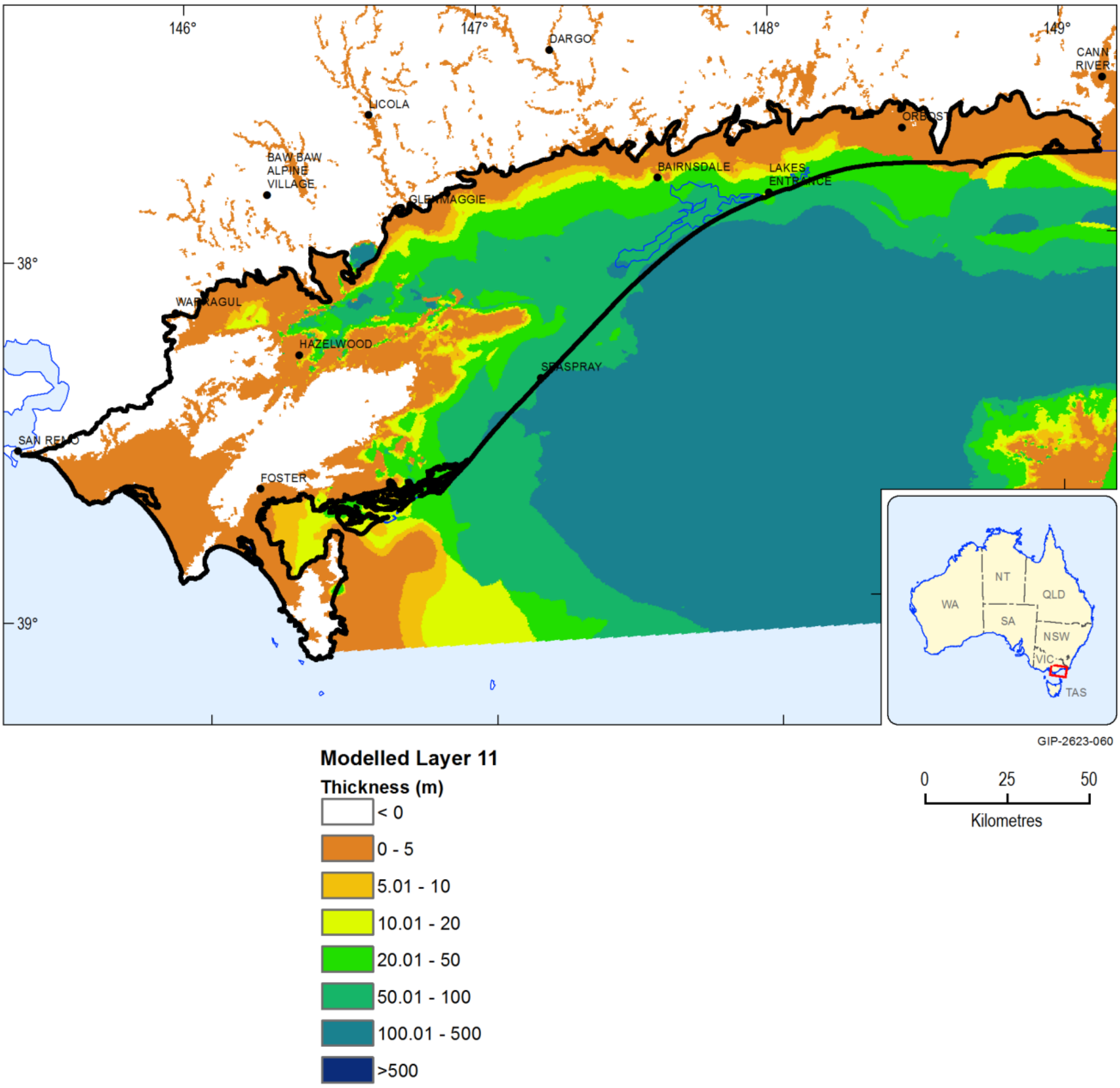


Figure 70 Thickness of modelled layer 11

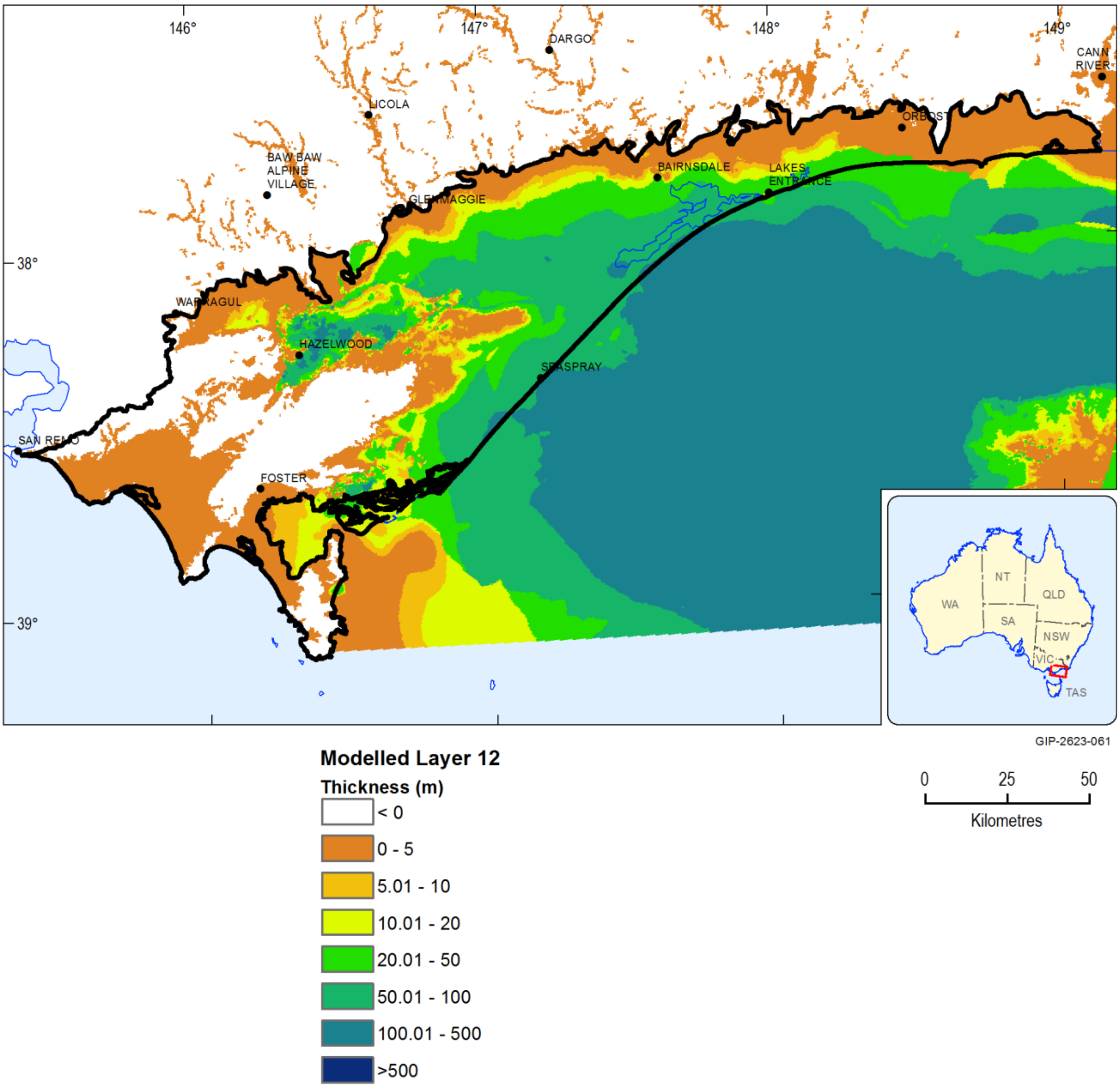


Figure 71 Thickness of modelled layer 12

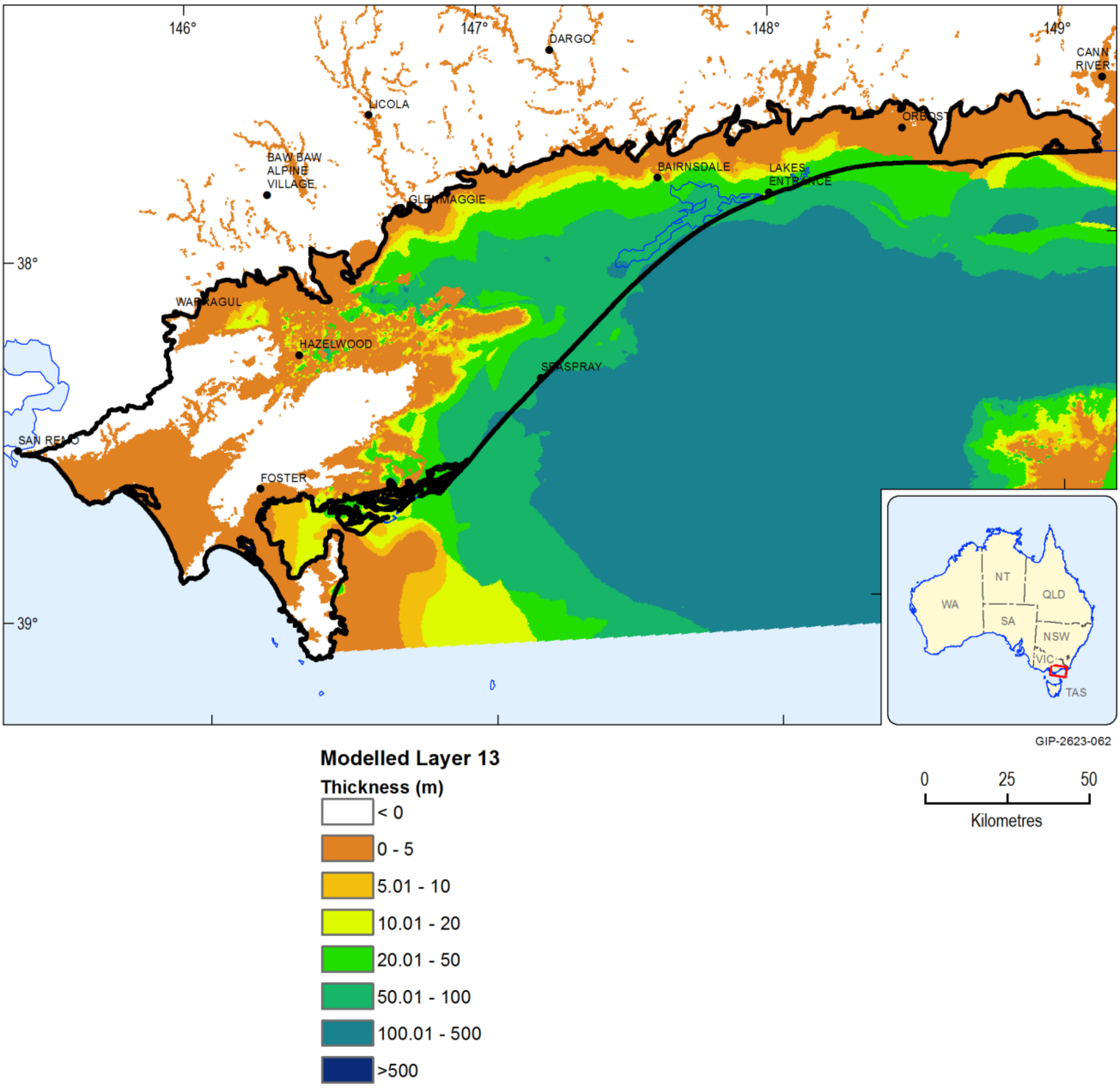


Figure 72 Thickness of modelled layer 13

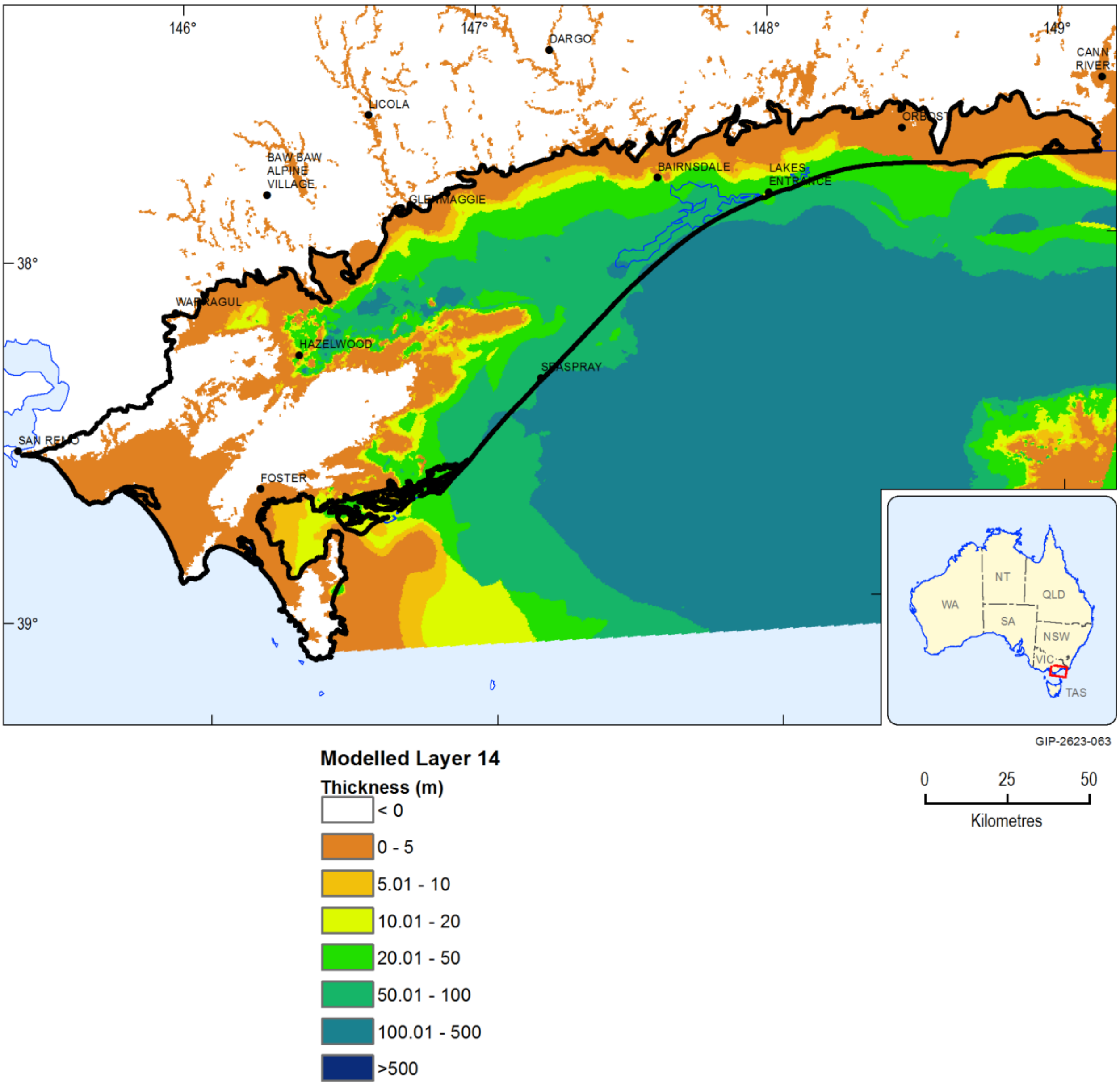


Figure 73 Thickness of modelled layer 14

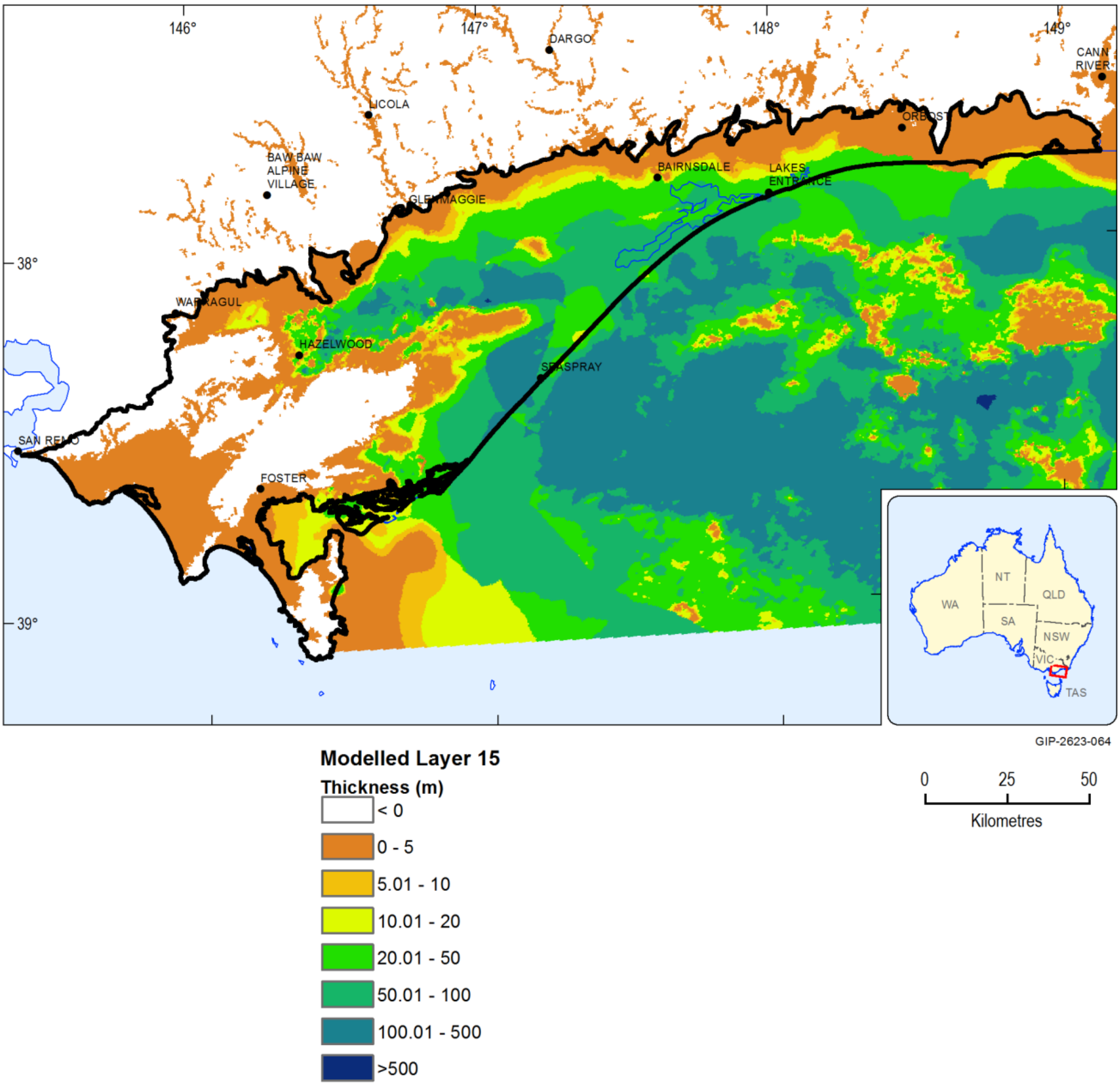


Figure 74 Thickness of modelled layer 15

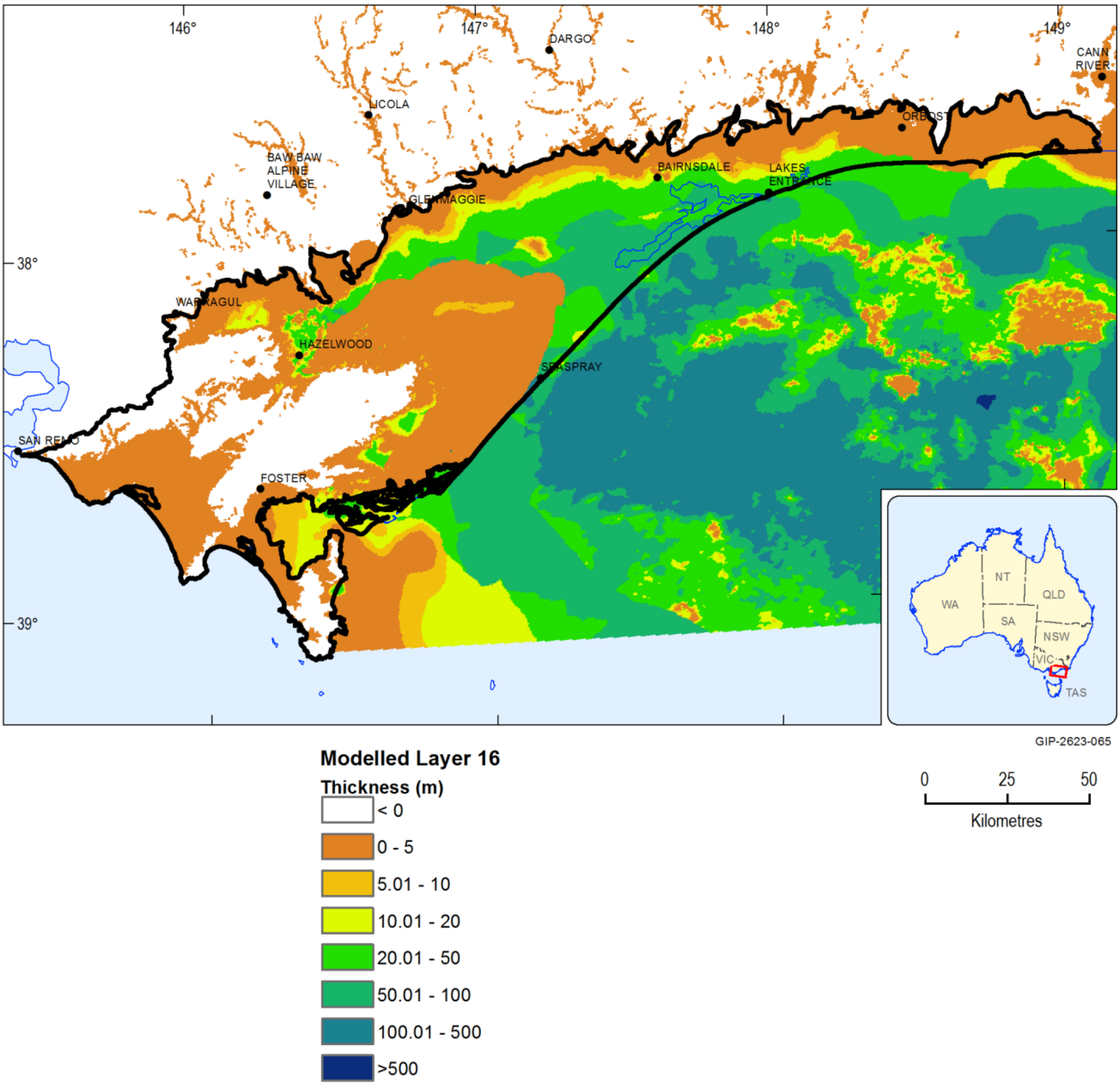


Figure 75 **Thickness of modelled layer 16**

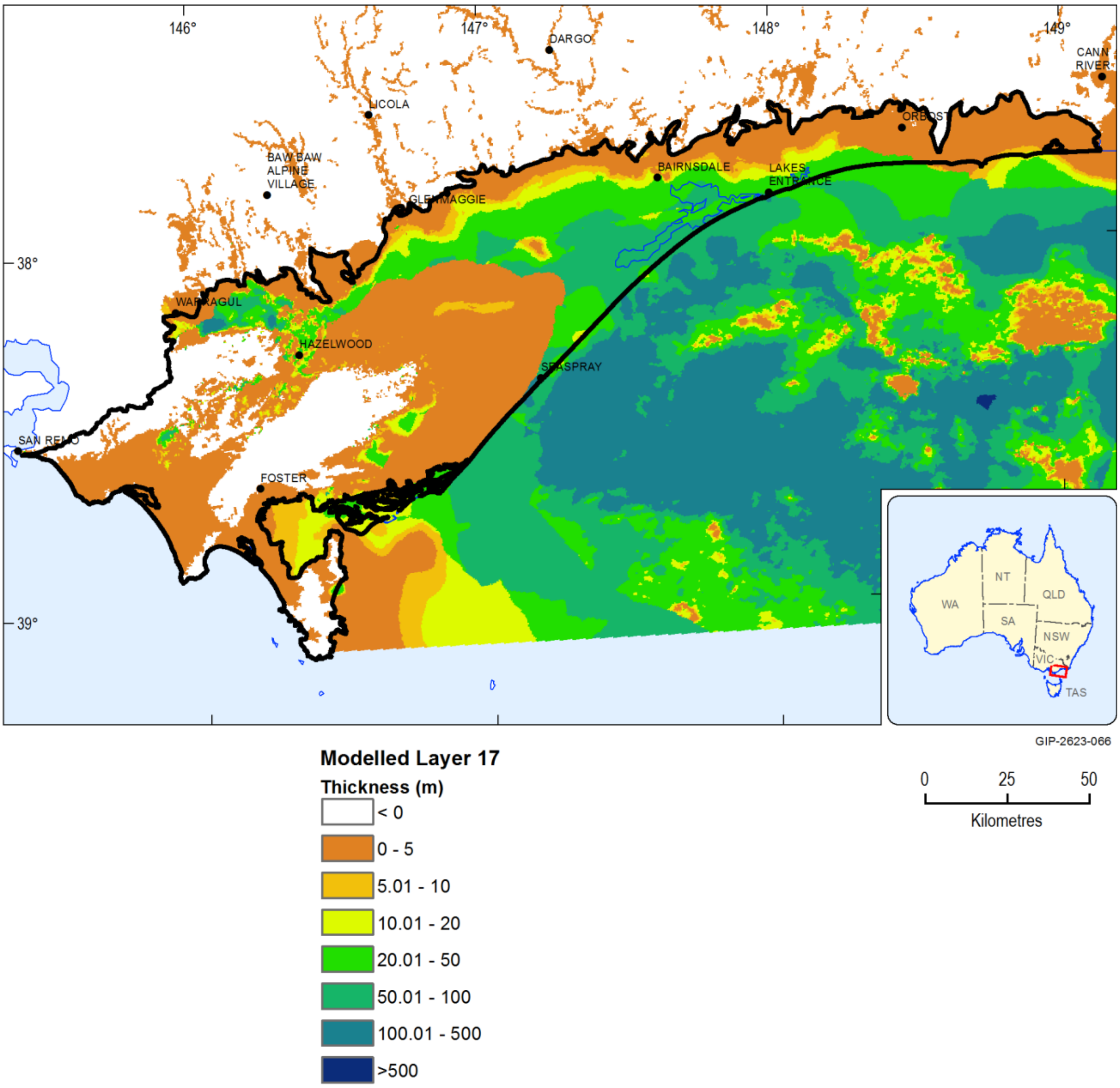


Figure 76 Thickness of modelled layer 17

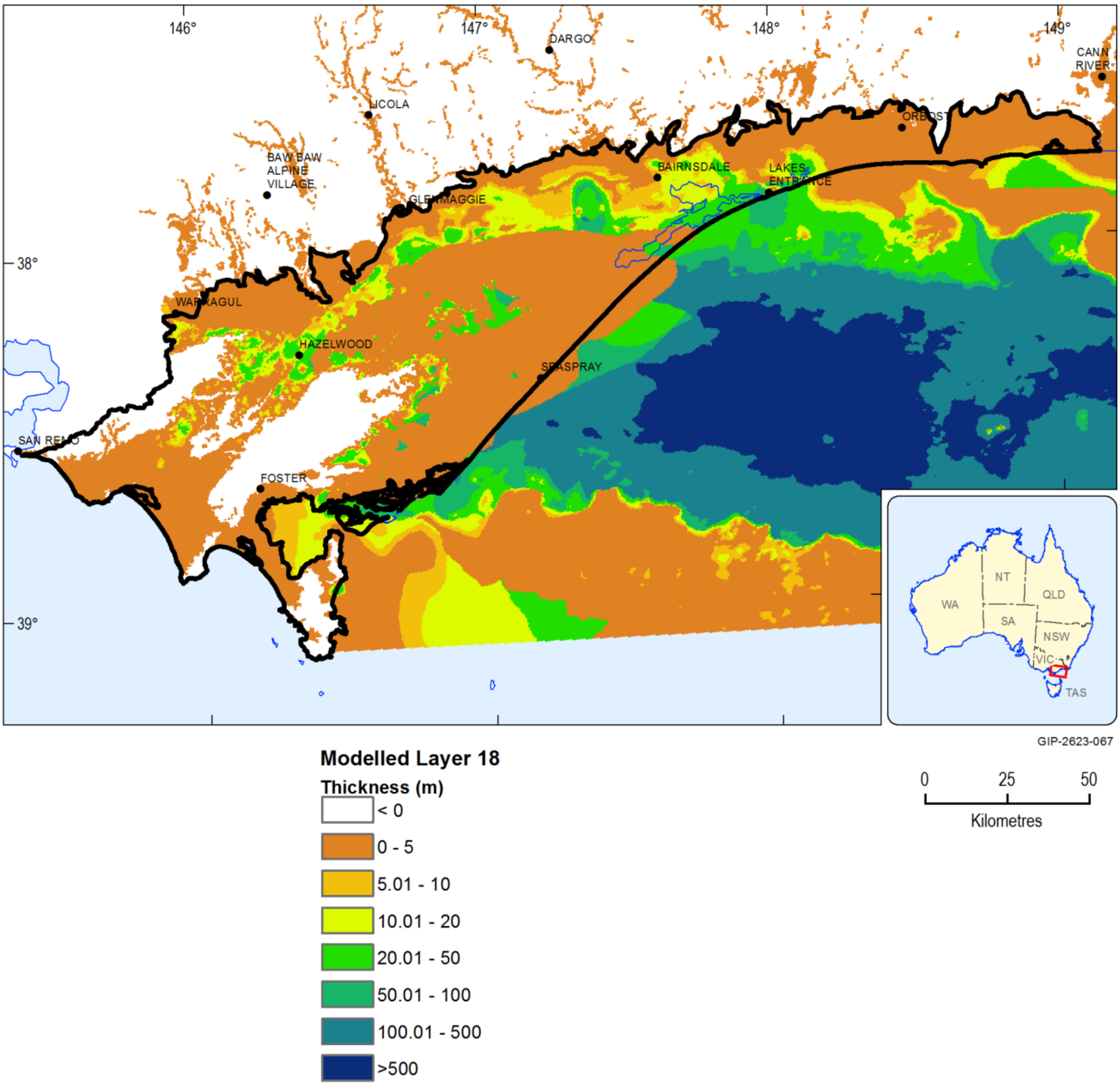


Figure 77 Thickness of modelled layer 18

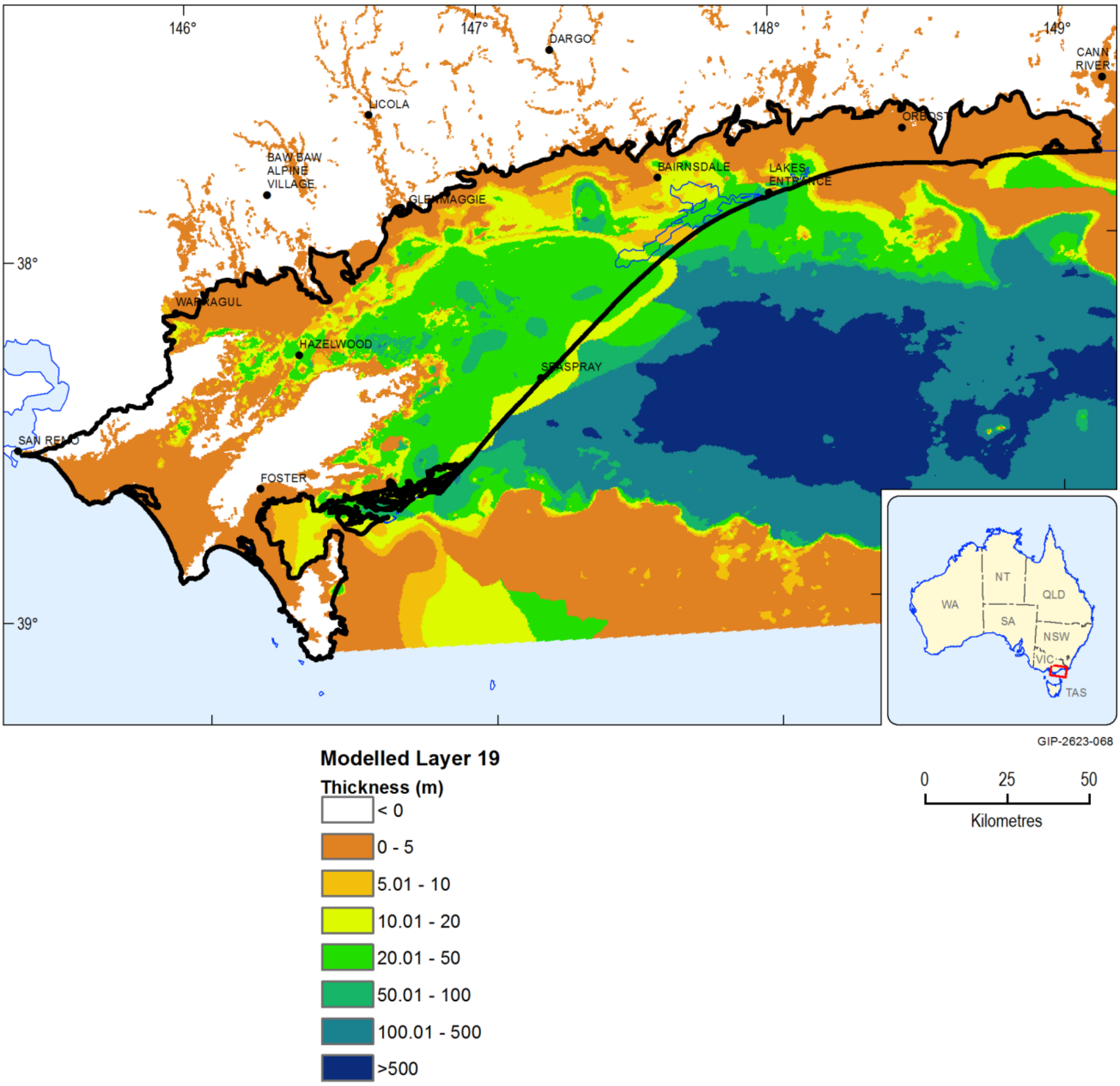


Figure 78 Thickness of modelled layer 19

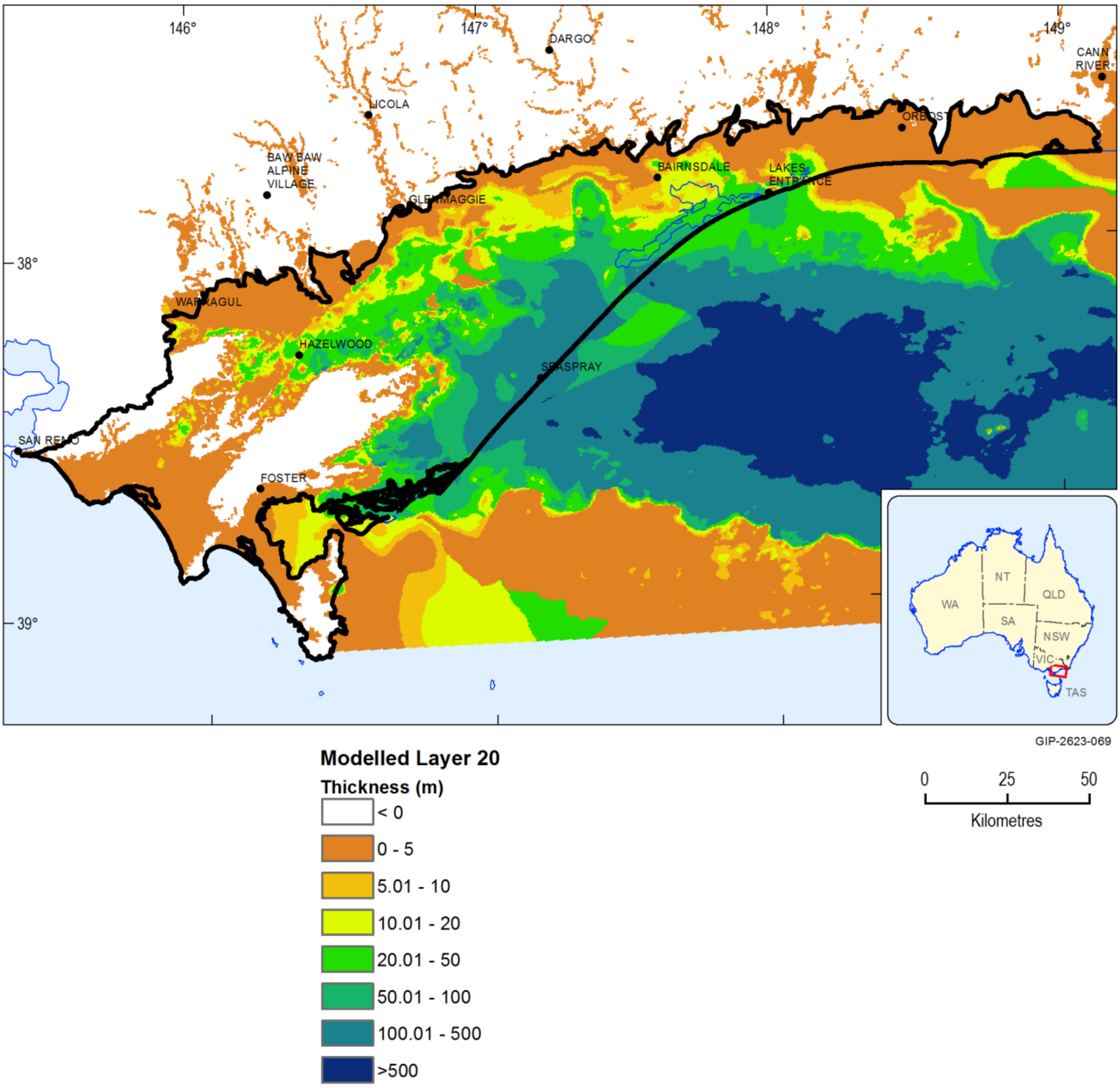


Figure 79 Thickness of modelled layer 20

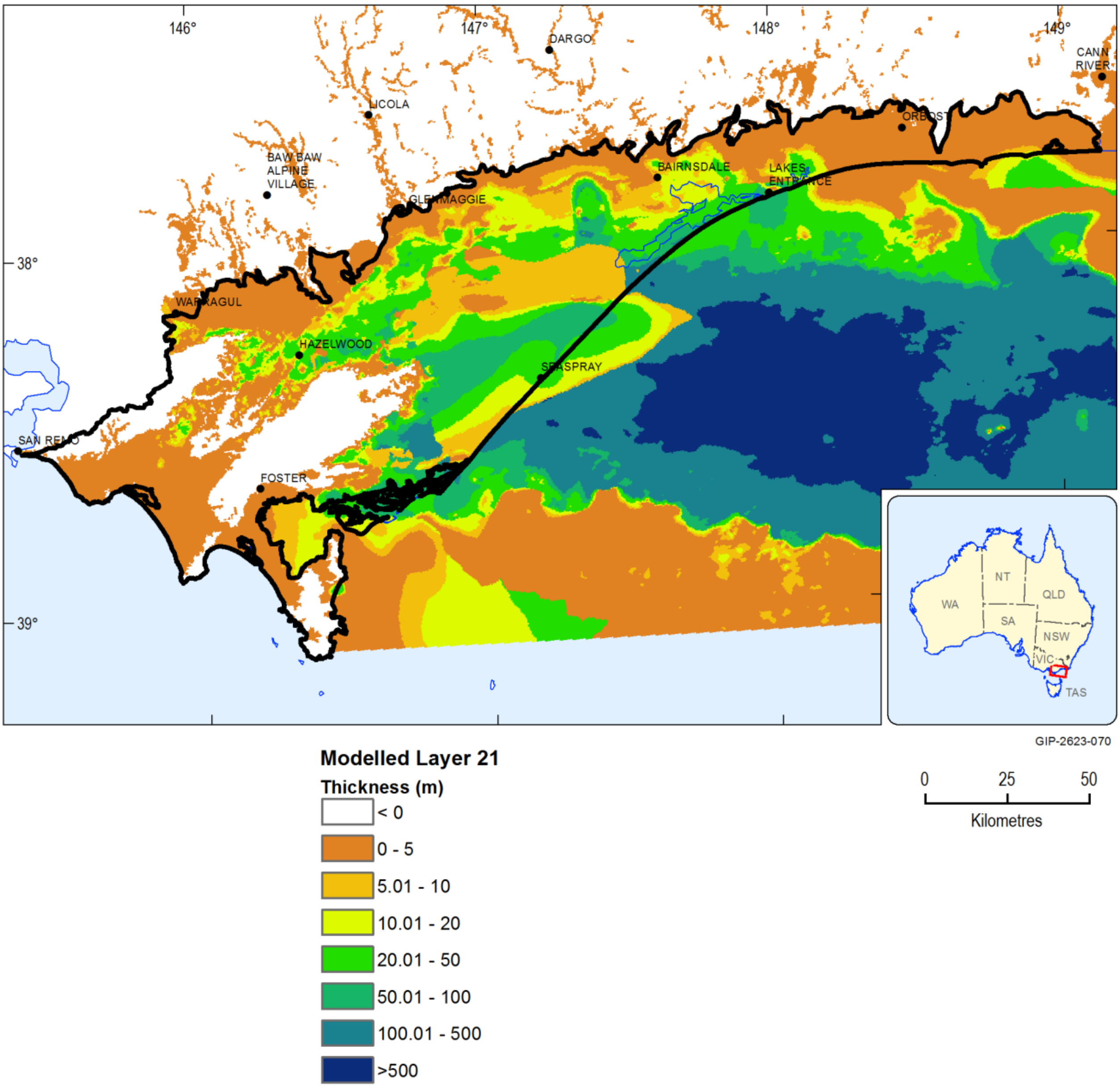


Figure 80 Thickness of modelled layer 21

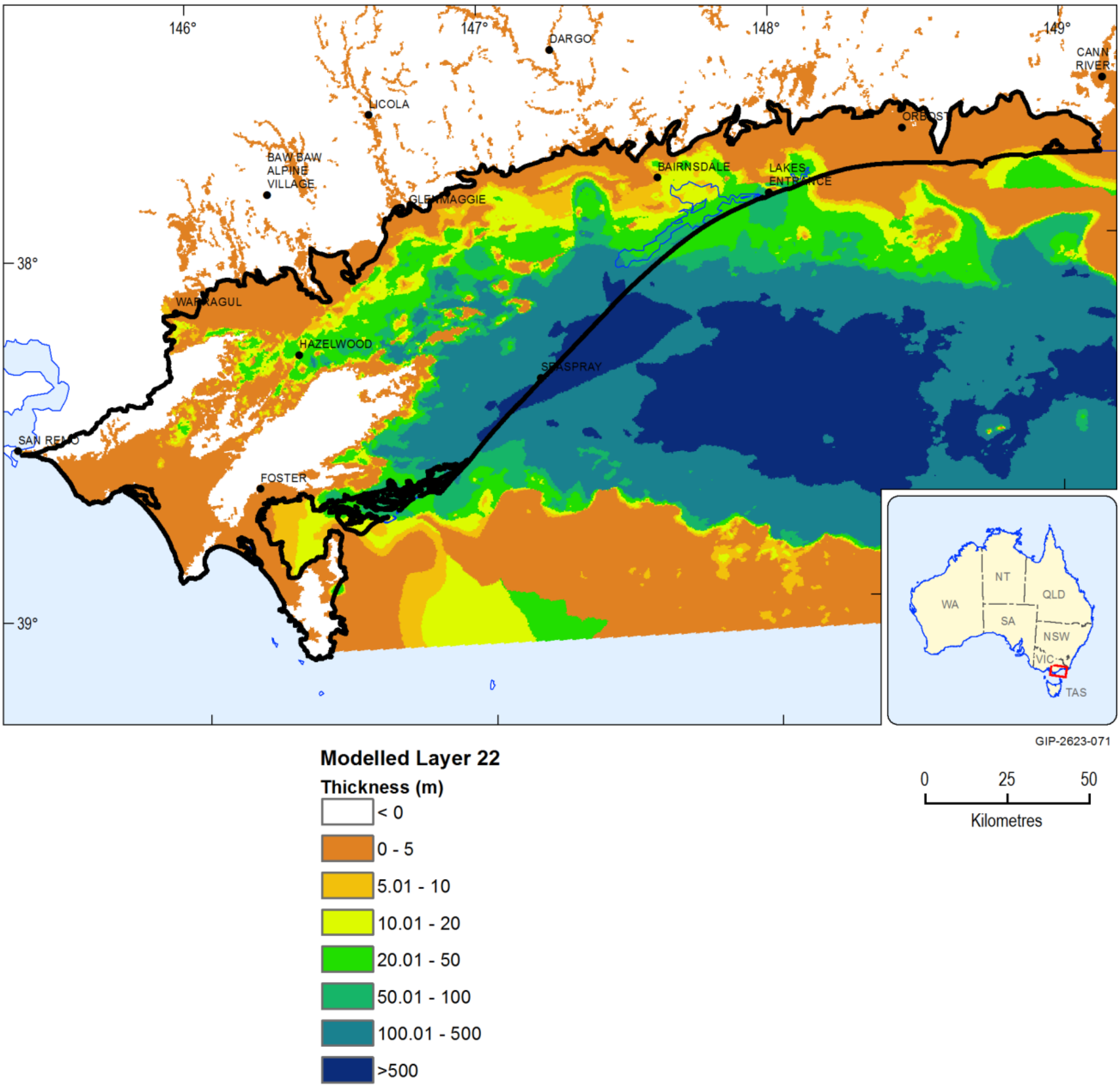


Figure 81 Thickness of modelled layer 22

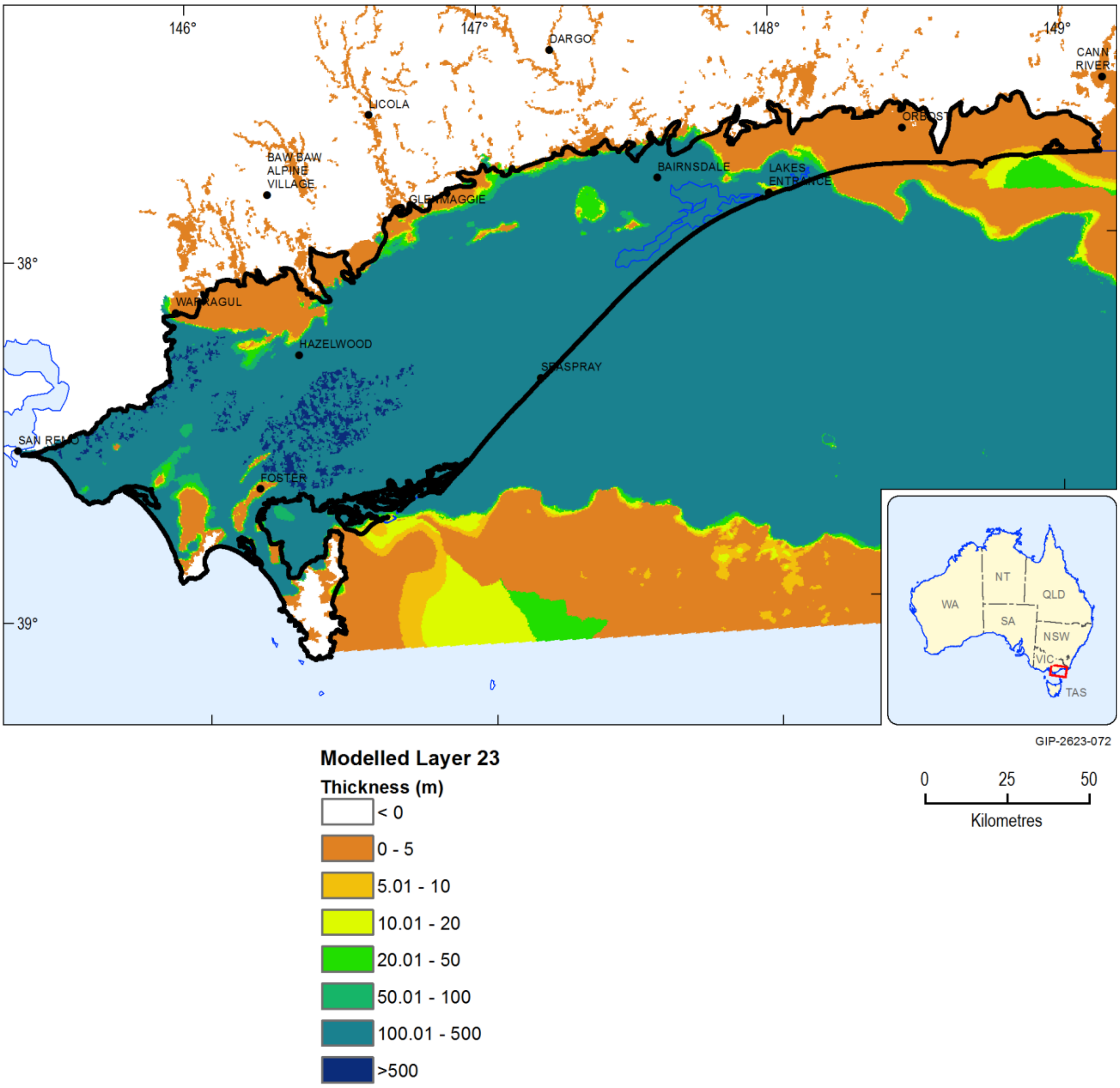


Figure 82 Thickness of modelled layer 23

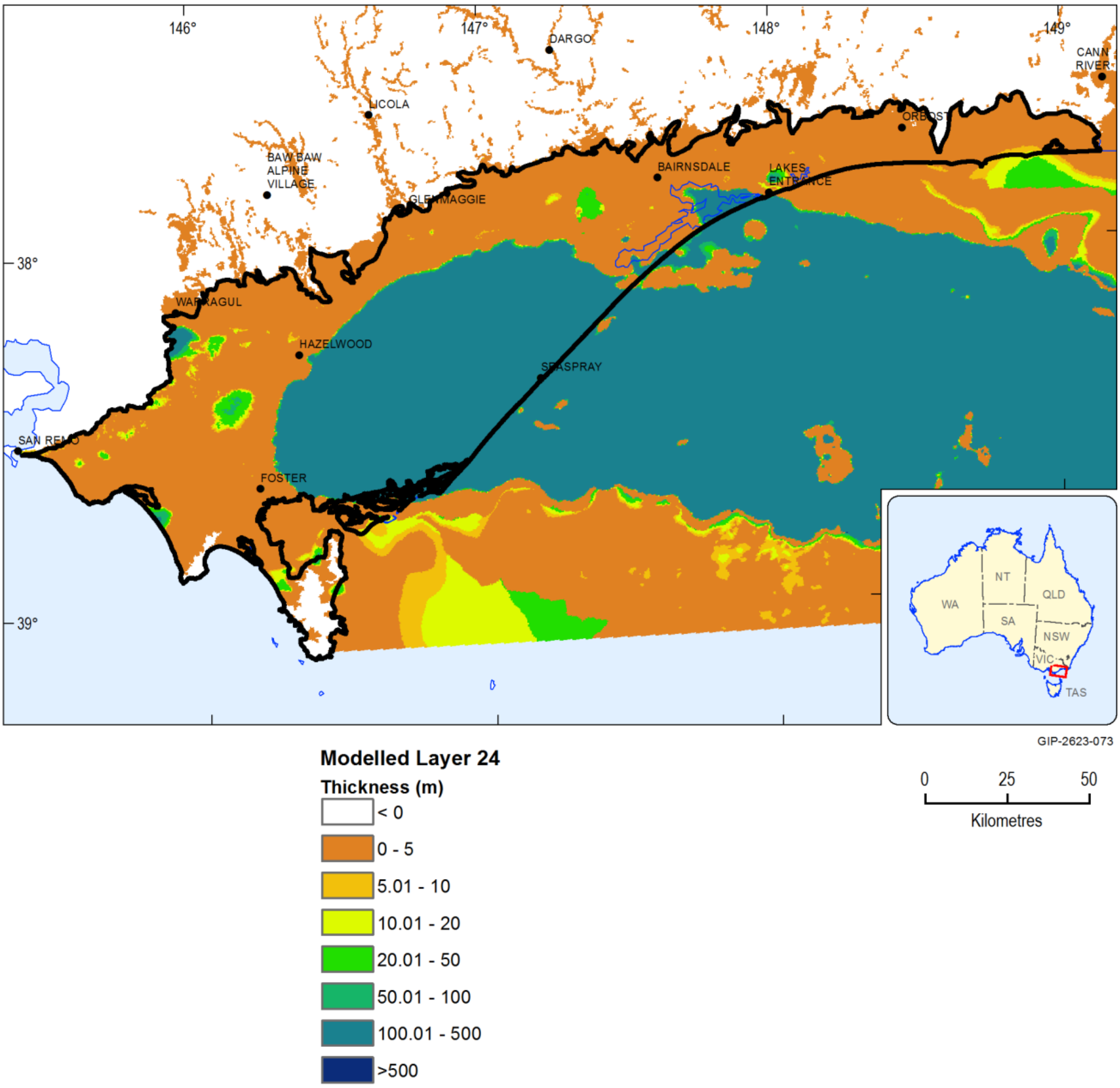


Figure 83 Thickness of modelled layer 24

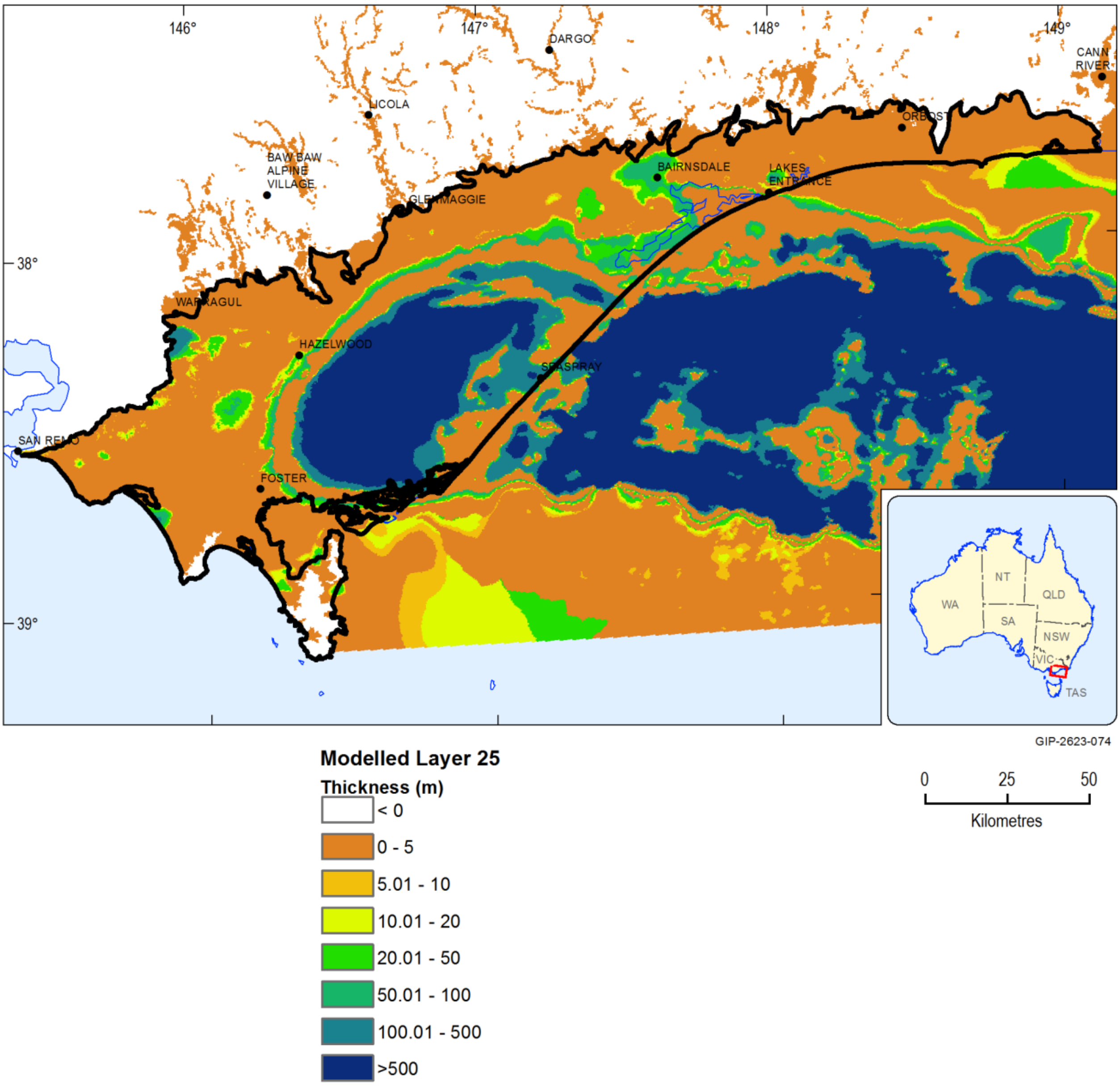


Figure 84 Thickness of modelled layer 25

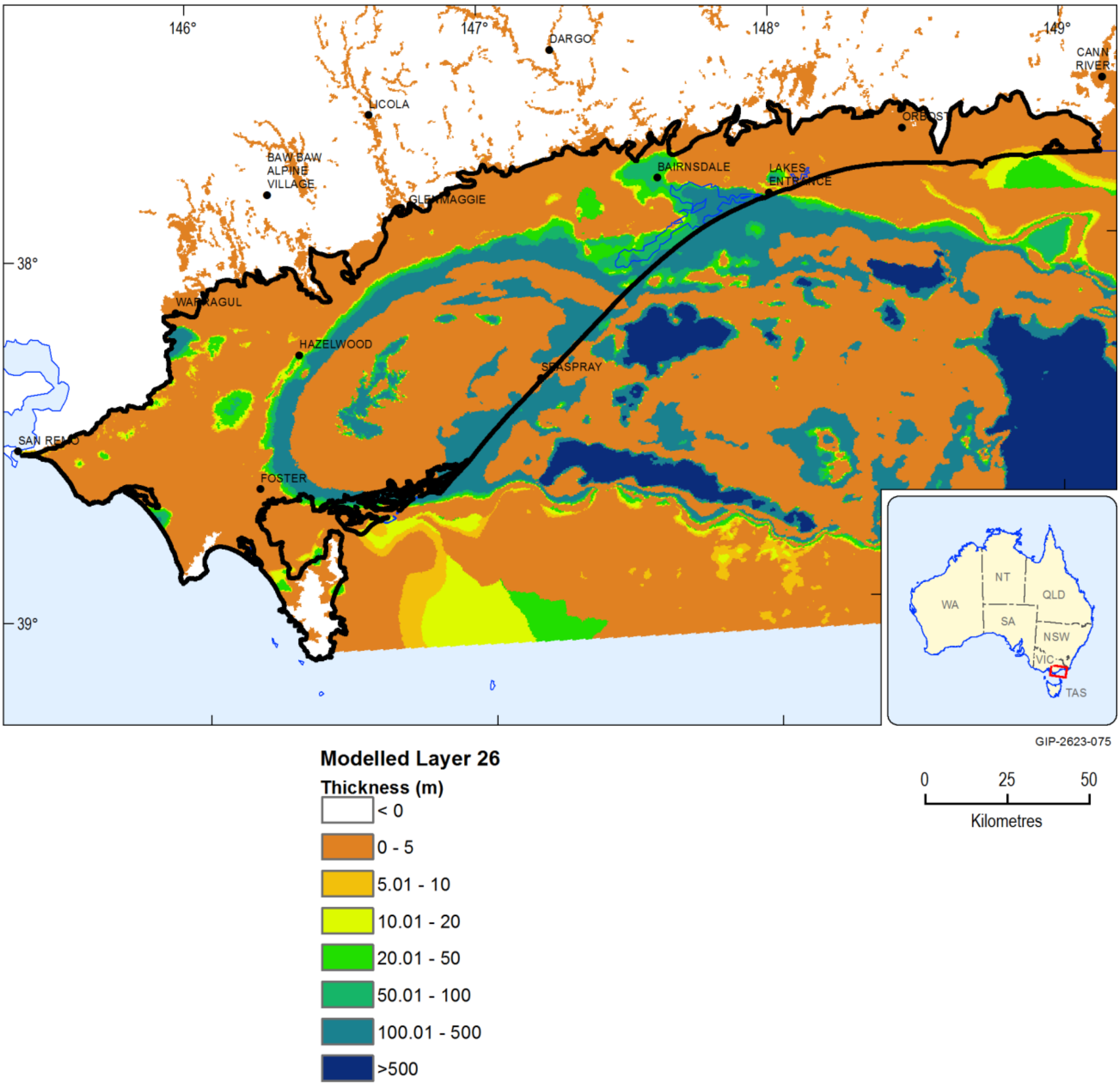


Figure 85 Thickness of modelled layer 26

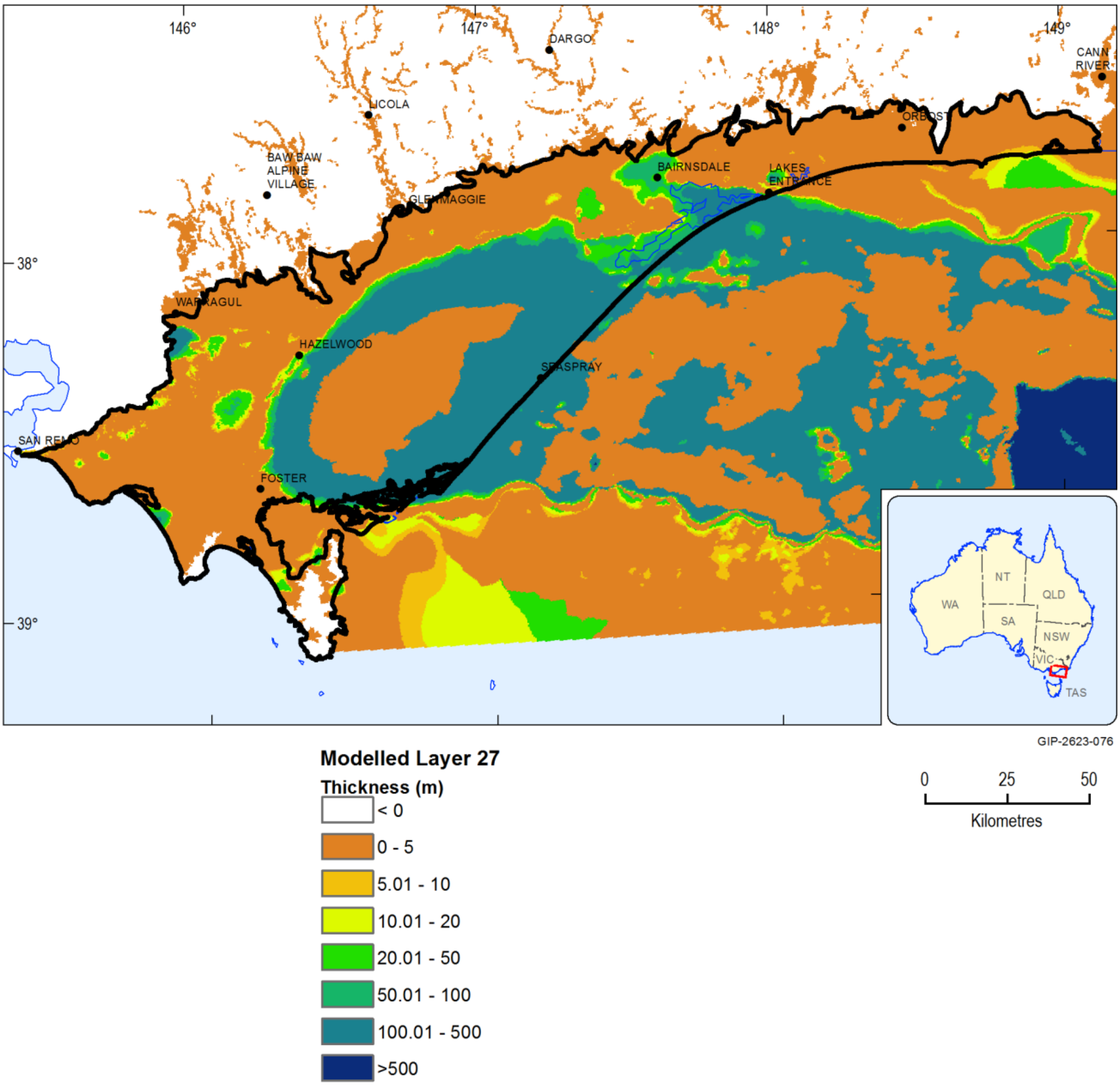


Figure 86 Thickness of modelled layer 27

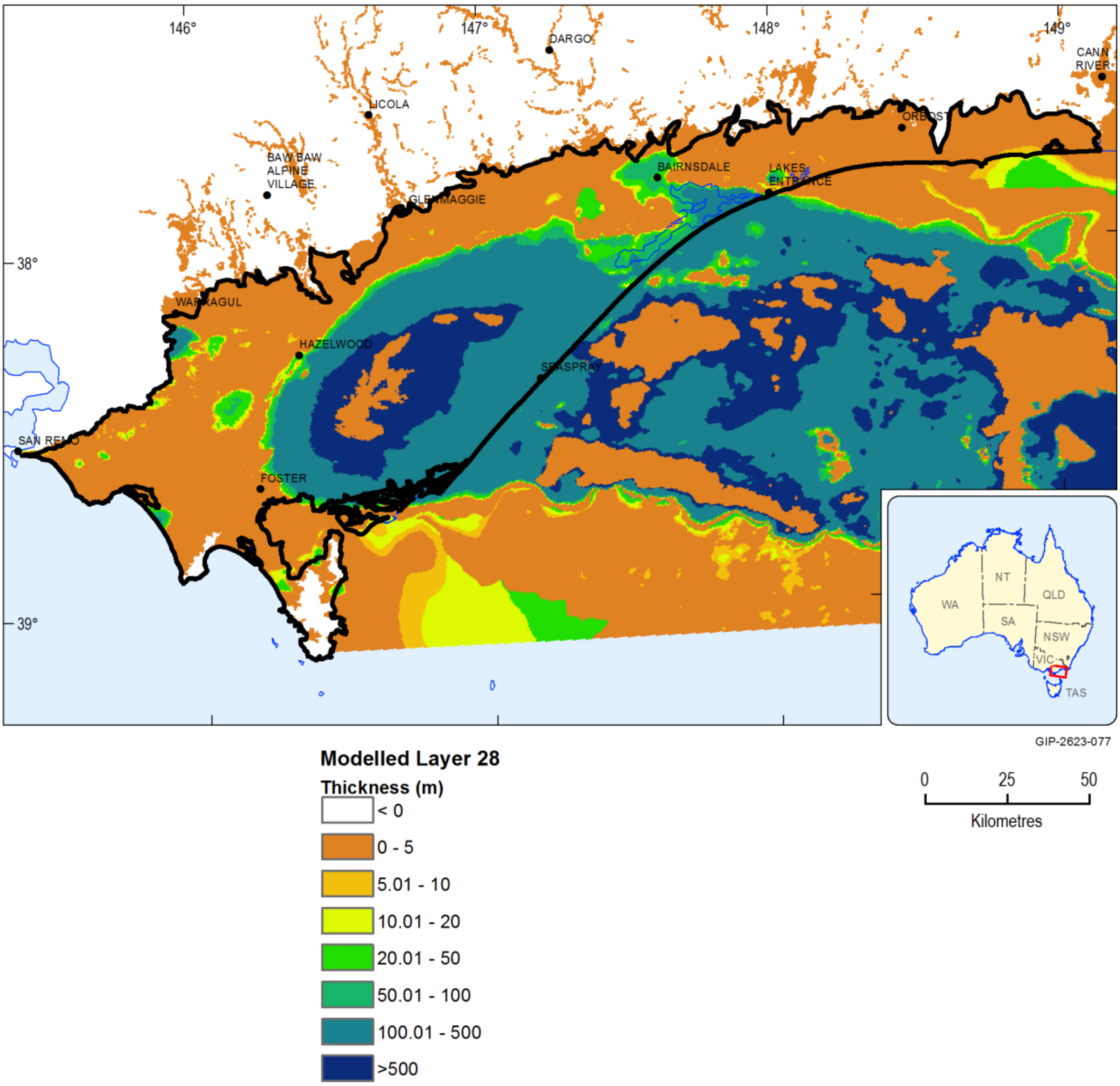


Figure 87 Thickness of modelled layer 28

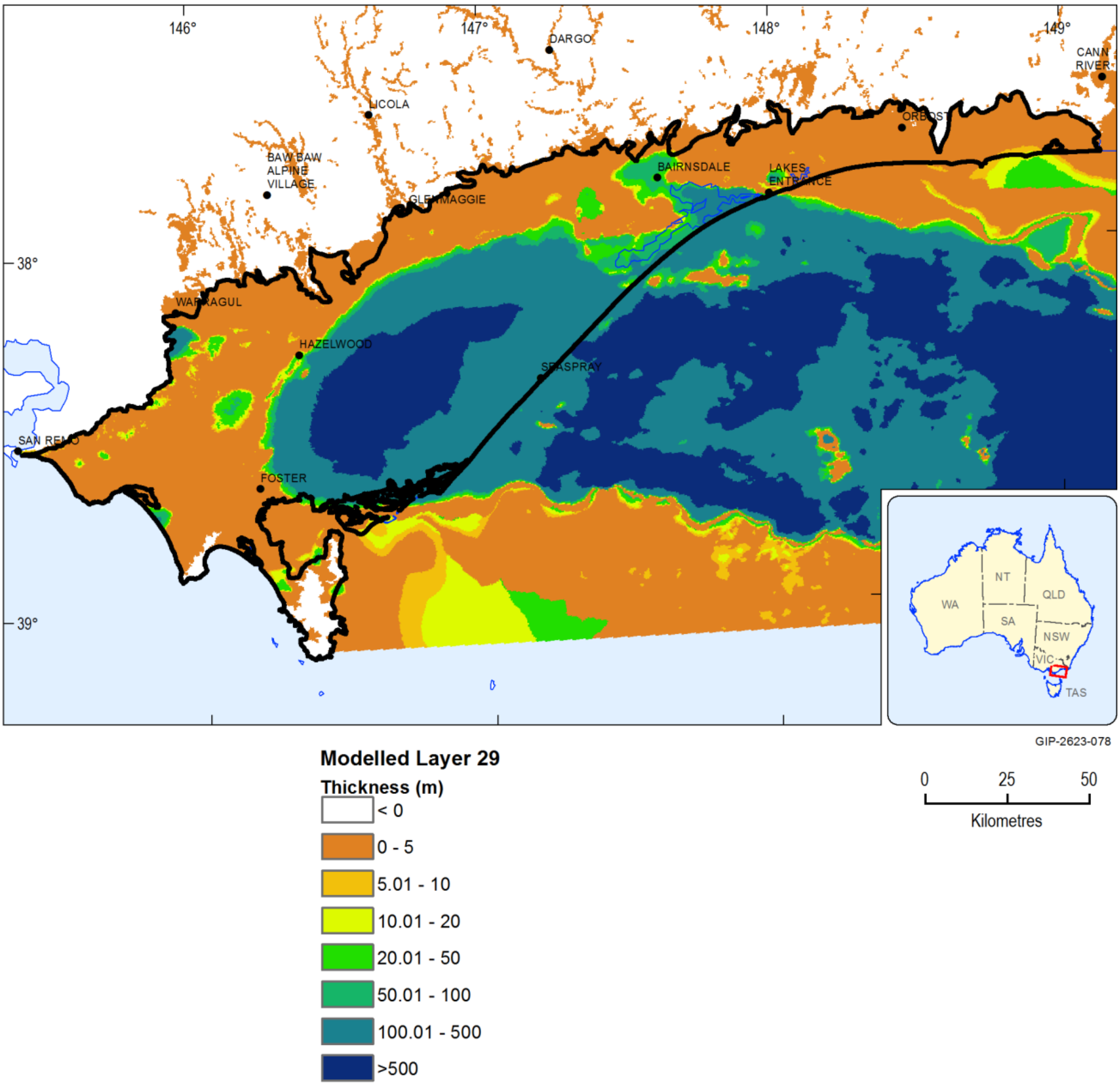


Figure 88 Thickness of modelled layer 29

2.6.2.4 Boundary and initial conditions

Summary

The boundaries of the regional model coincide with the geological basin and are implemented as no flow boundaries. A total of 22,573 river boundary cells were incorporated into the model to represent major river reaches, whereas 410,504 drain cells were assigned to capture surface expressions of groundwater. Recharge and potential groundwater evapotranspiration rates were derived using a catchment modelling framework that accounted for episodic flooding and assigned as fixed inputs into the groundwater model. Initial conditions were based on 1970 observation data.

2.6.2.4.1 Sources of boundary and calibration data

Time series calibration information was sourced from on-line databases as summarised in Table 8. An assessment of the confidence of each key data set is also included based on criteria that considered:

- expertise of those groups responsible for data collection and collation
- processes for consistency of field measurement
- processes used to quality assure data
- data management and custodianship
- degree of acceptance of data robustness by other groups and end-users.

Table 8 Source of time-series data incorporated into the groundwater model

Time-series data	Source	Confidence in data
Groundwater level	Victorian Water Measurement Information System (http://data.water.vic.gov.au/monitoring.htm)	High
Surface water level	Victorian Water Measurement Information System (http://data.water.vic.gov.au/monitoring.htm)	High
Baseflow	SKM reports and derived estimates from Victorian Water Measurement Information System (http://data.water.vic.gov.au/monitoring.htm)	Moderate
Flood mapping	Department of Environmental and Primary Industries	
Groundwater extraction (onshore)	Southern-Rural Water, Water, Department of Environmental and Primary Industries	Moderate to High; some data has been inferred and some actual
Groundwater extraction (offshore)	Volume equivalent groundwater extractions associated with offshore oil and gas operations were sourced from Hatton, et al (2004) and Varma, et al (2012)	Moderate
Mine floor elevations	Department of Environmental and Primary Industries	Moderate
Climatic data	Bureau of Meteorology (http://www.bom.gov.au/climate/)	High

2.6.2.4.2 Groundwater model layer boundary conditions

Groundwater boundary conditions are features which influence groundwater flow. In a groundwater modelling context, boundary conditions are constraints imposed onto the model to reflect an area which is influenced by external features (such as wells, rivers, no-flow barriers, etc.). Groundwater flow boundary conditions considered in this study are listed below.

- No flow boundary – represents locations where groundwater does not flow and/or the aquifer is absent; such features include groundwater divides (specified flow boundary type).
- Well boundary – represents locations where fluxes are applied to the model (on a layer-by-layer basis). They are used to represent groundwater extraction from stock, domestic and industrial bores and from groundwater pumping in offshore oil and gas fields.
- River boundary – represents a head dependent boundary condition where groundwater can either recharge or discharge into/from the model based upon a specified head elevation, the model-predicted head in neighbouring cells and a specified boundary conductance term. Rivers in this model have been grouped as either major or minor rivers. Major rivers represent primary tributaries and were assigned a width and depth of 20 m with a stage of 4 m from the

base. Minor rivers were considered as significant tributaries and assigned a width and depth of 10 m and a stage of 2 m from the base. In the absence of river bed elevation data, the base elevation was assumed to be surface elevation less 5 m for major rivers and surface elevation less 2 m for minor rivers.

- Drain boundary – represents a head dependent boundary condition where water is removed from the model depending on the specified head elevation, the predicted head in neighbouring cells and the specified boundary conductance term.
- Constant head boundary (time constant specified head) – represents flows into or out of the model domain where groundwater connects or interacts with features (and the ocean) outside the model domain.

Figure 89 to Figure 118 show the spatial assignment of boundary conditions to each of the modelled layers.

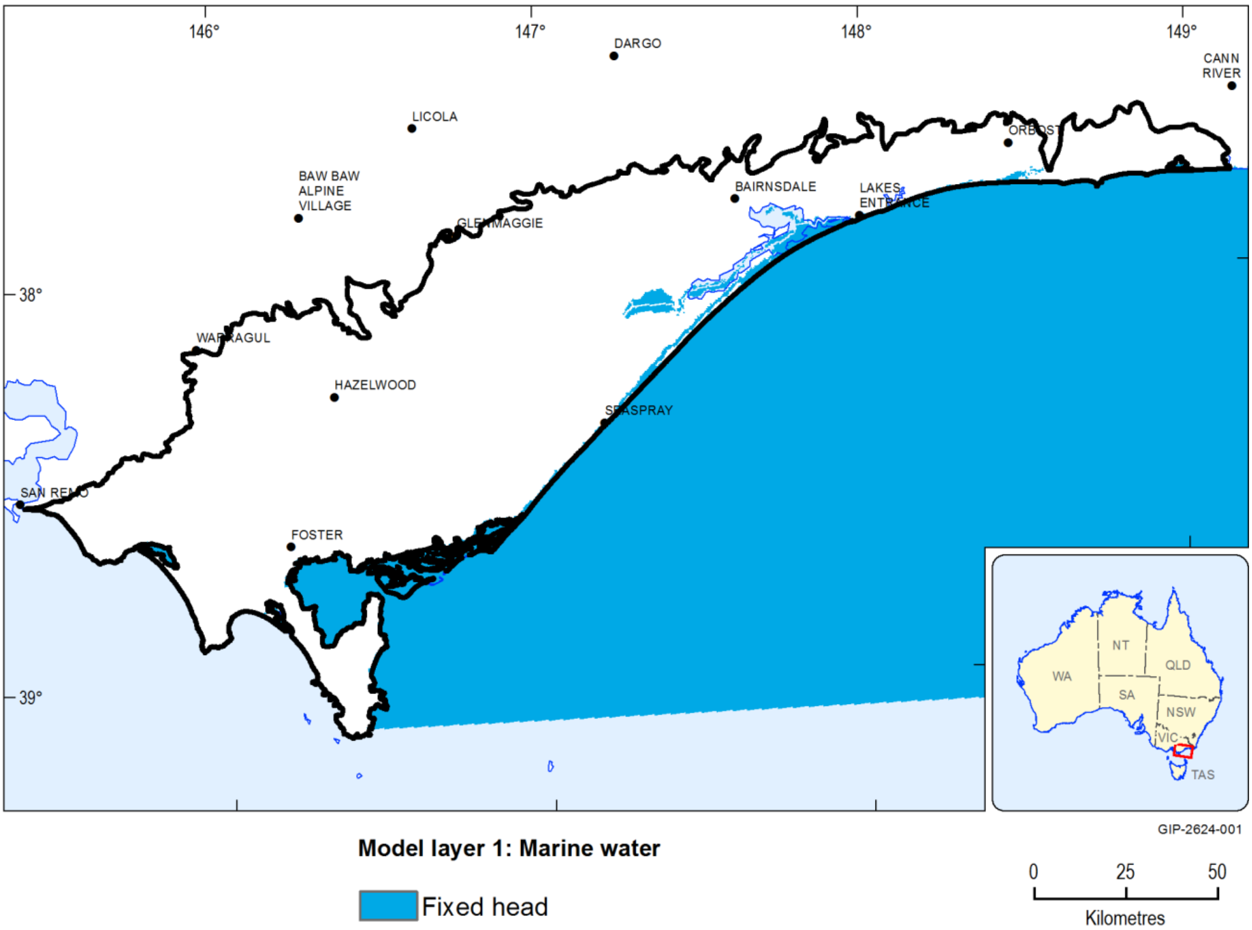


Figure 89 Boundary conditions of modelled layer 1

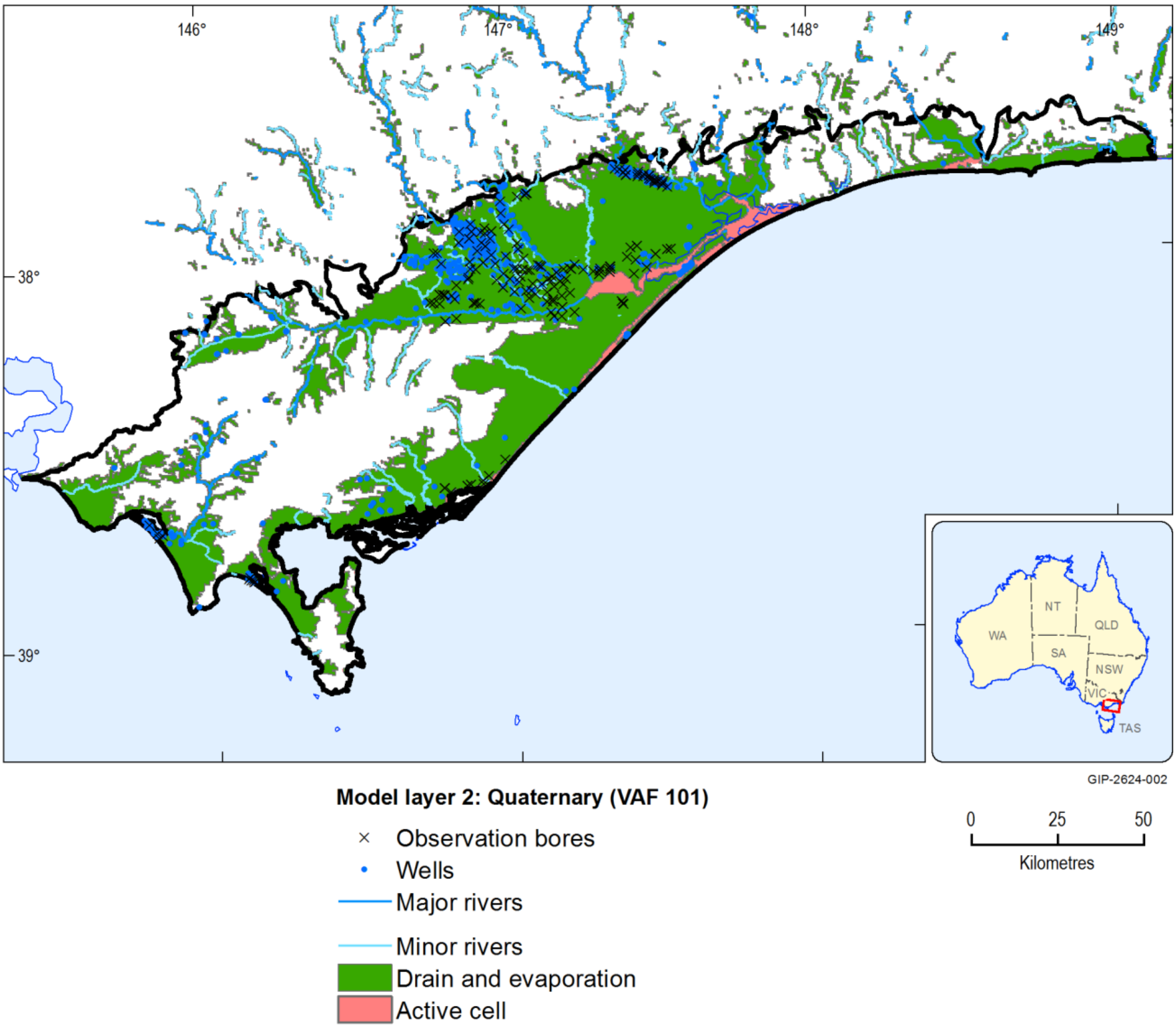


Figure 90 Boundary conditions of modelled layer 2

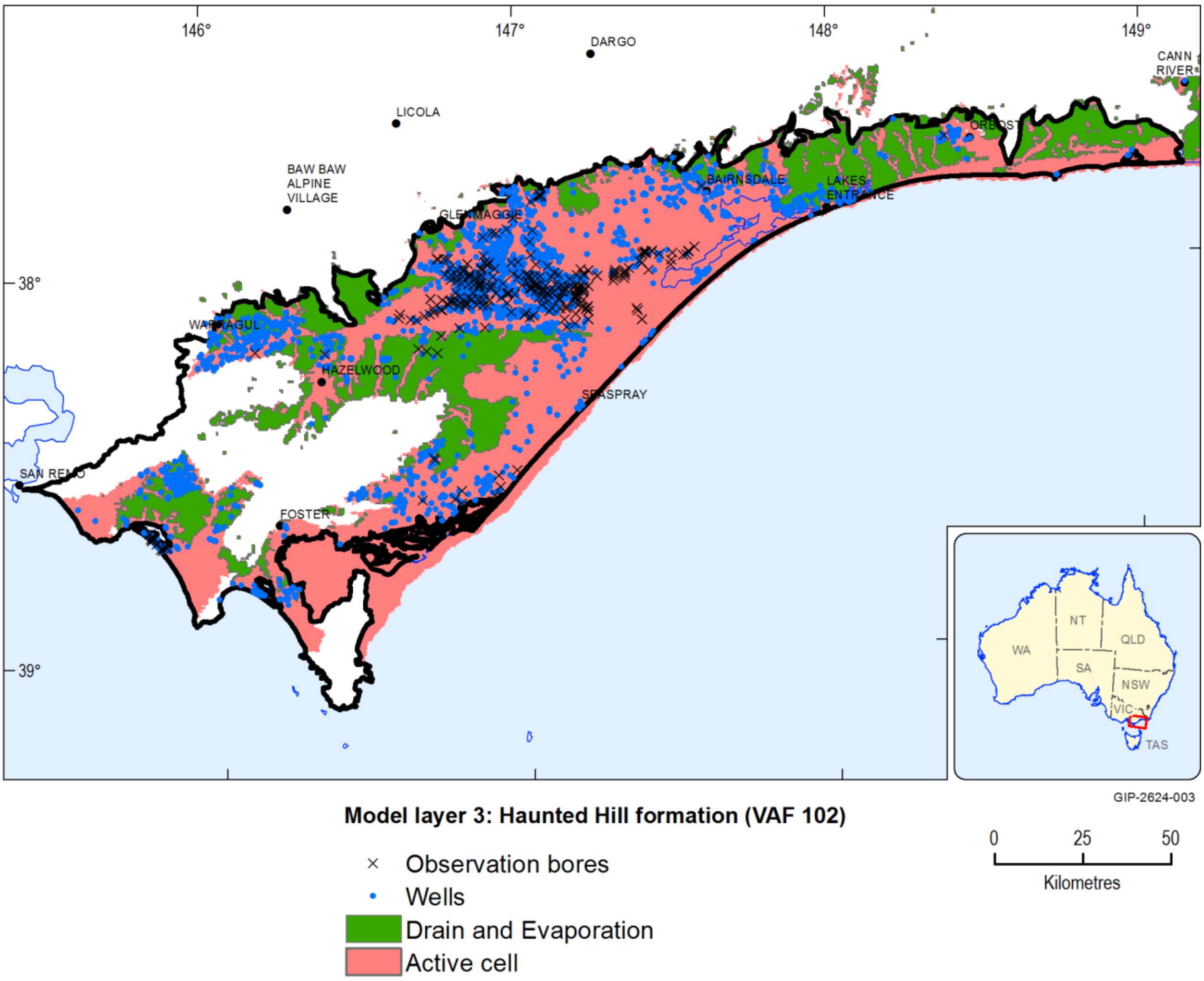


Figure 91 Boundary conditions of modelled layer 3

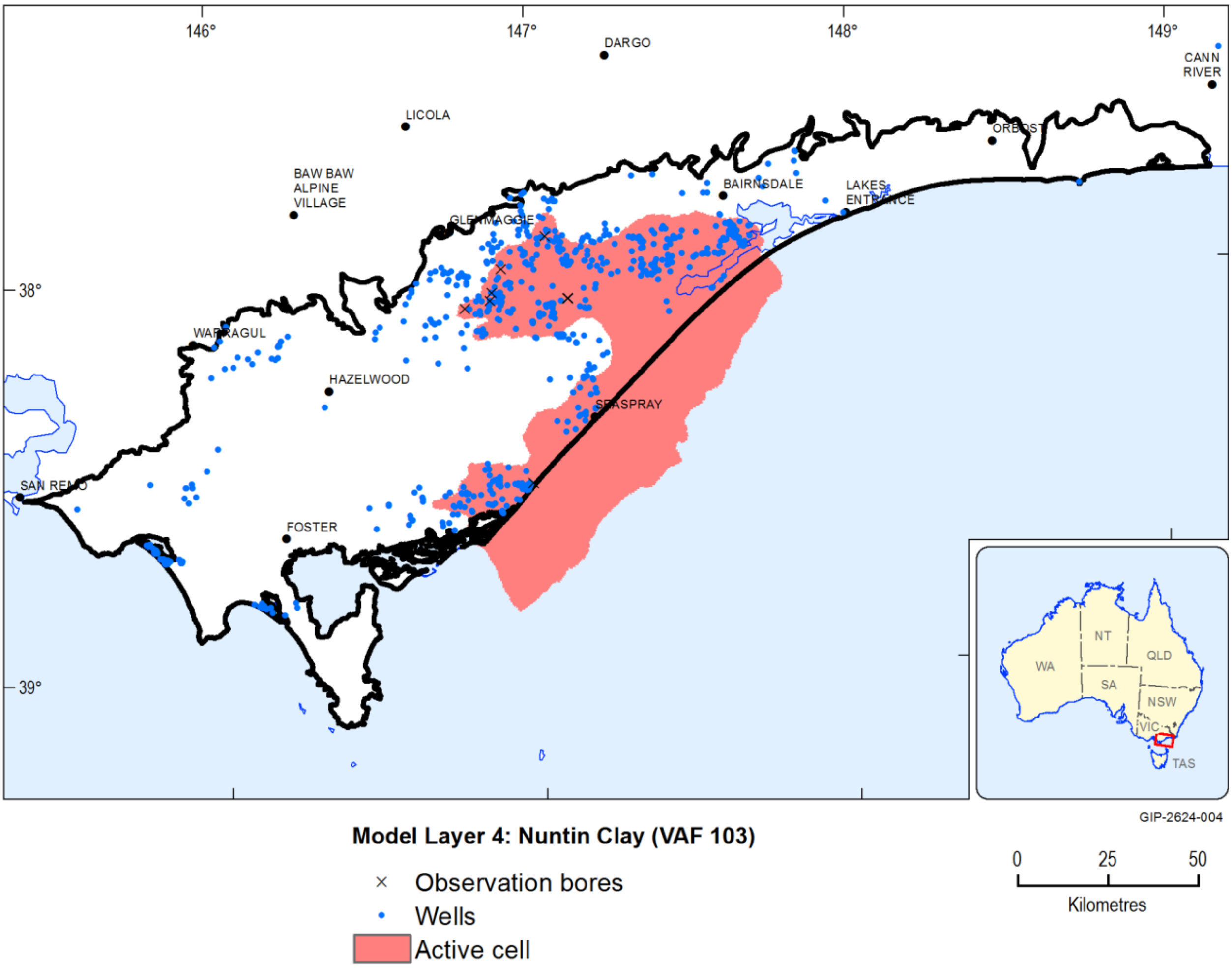


Figure 92 Boundary conditions of modelled layer 4

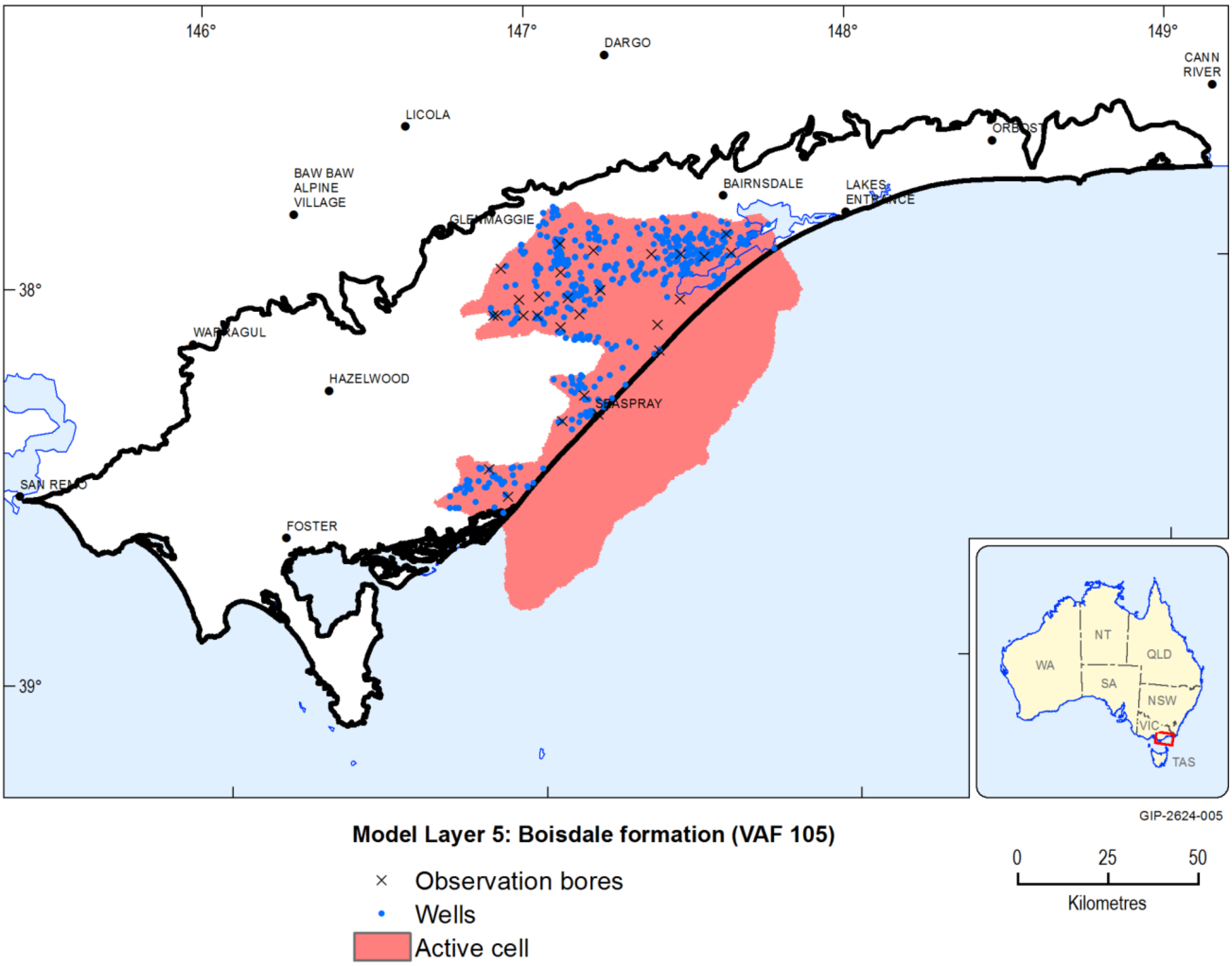


Figure 93 Boundary conditions of modelled layer 5

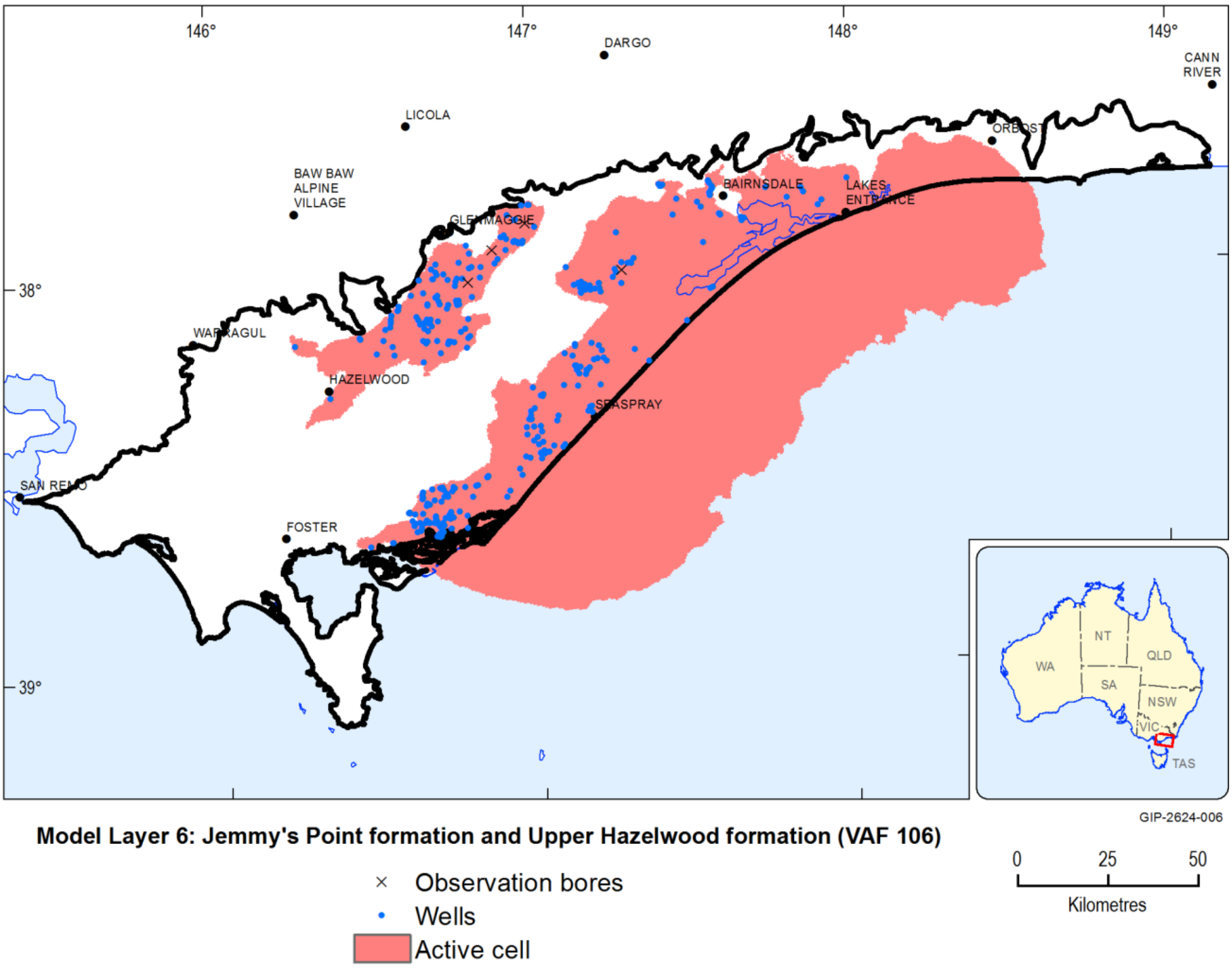


Figure 94 Boundary conditions of modelled layer 6

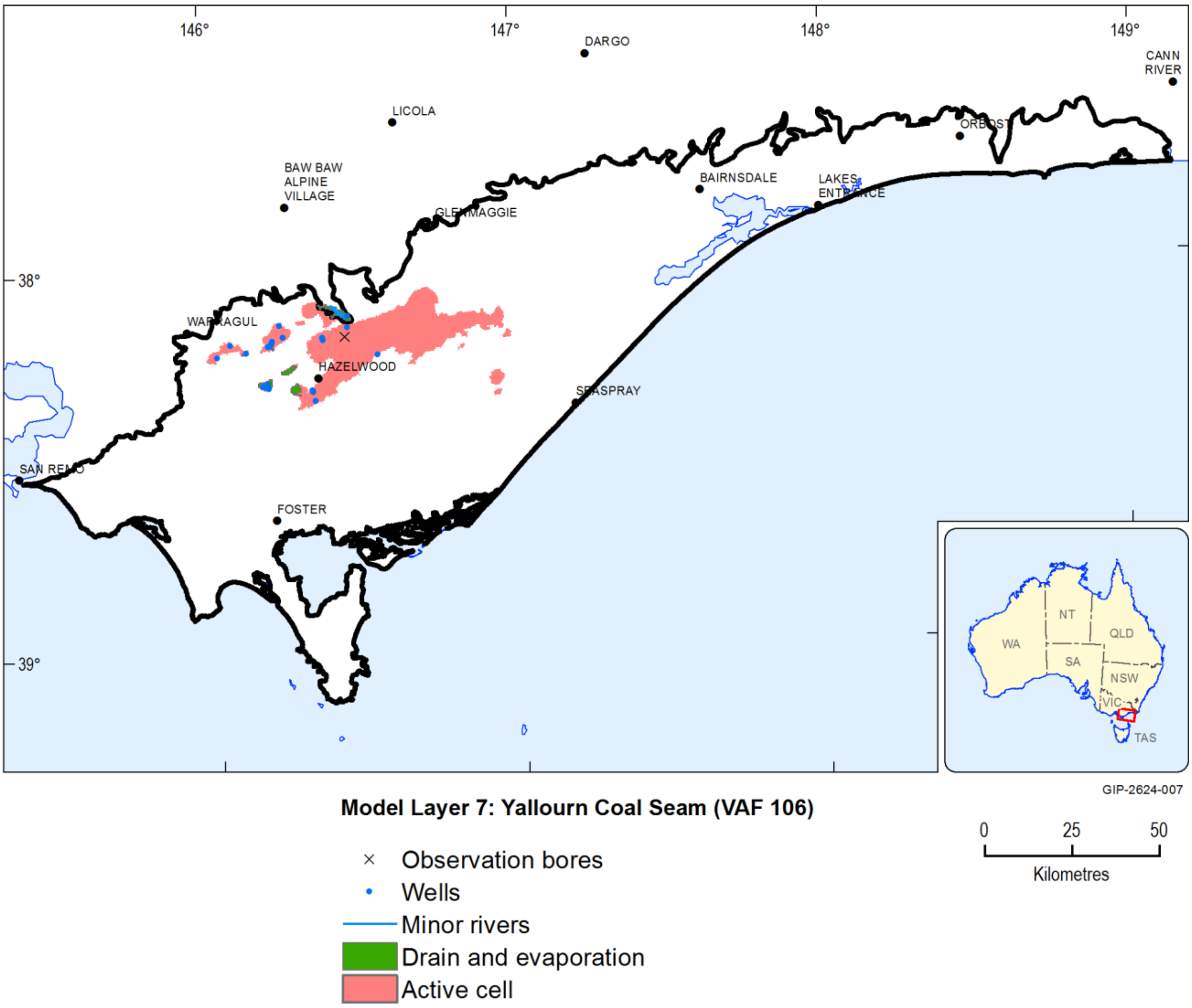


Figure 95 Boundary conditions of modelled layer 7

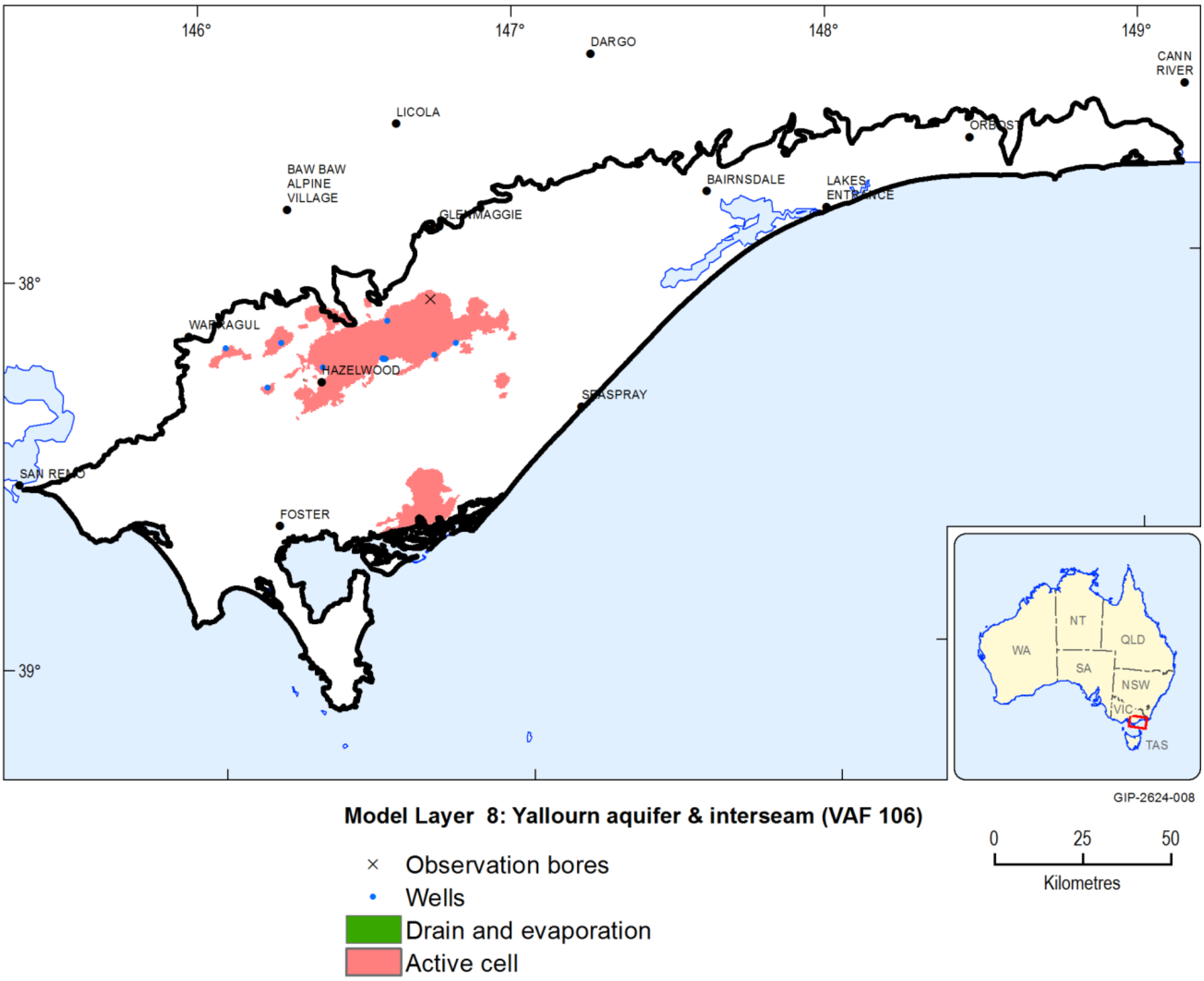


Figure 96 Boundary conditions of modelled layer 8

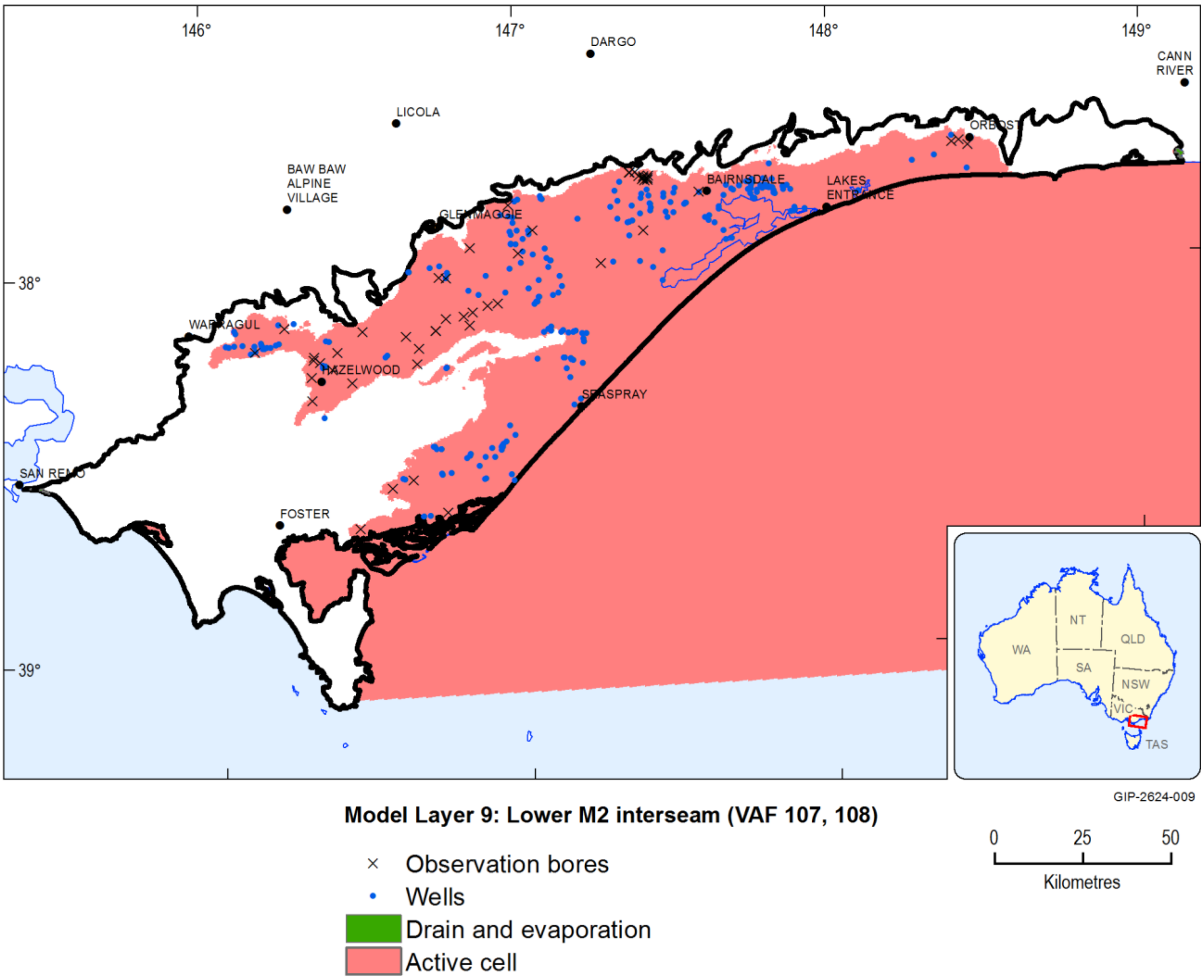


Figure 97 Boundary conditions of modelled layer 9

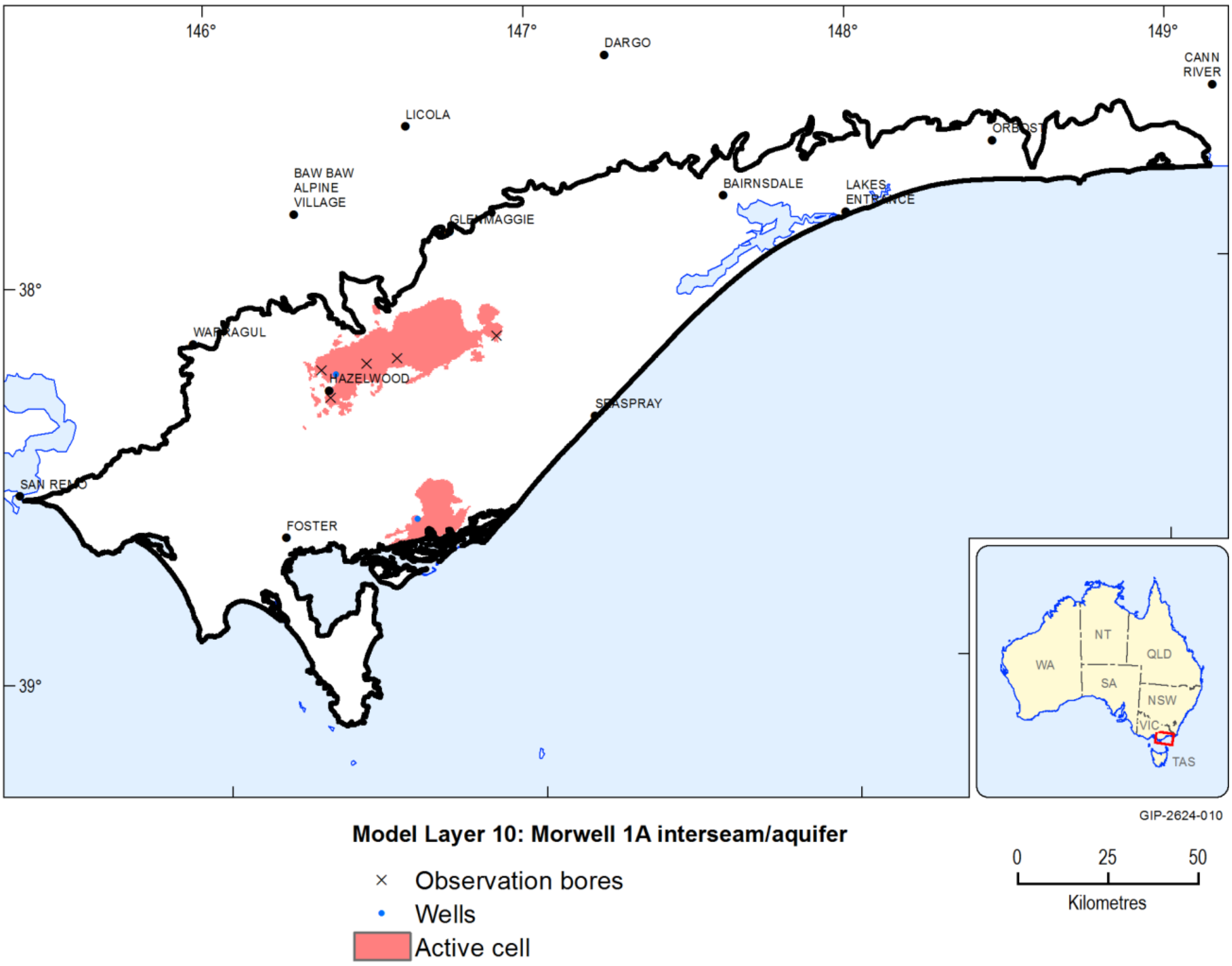


Figure 98 Boundary conditions of modelled layer 10.

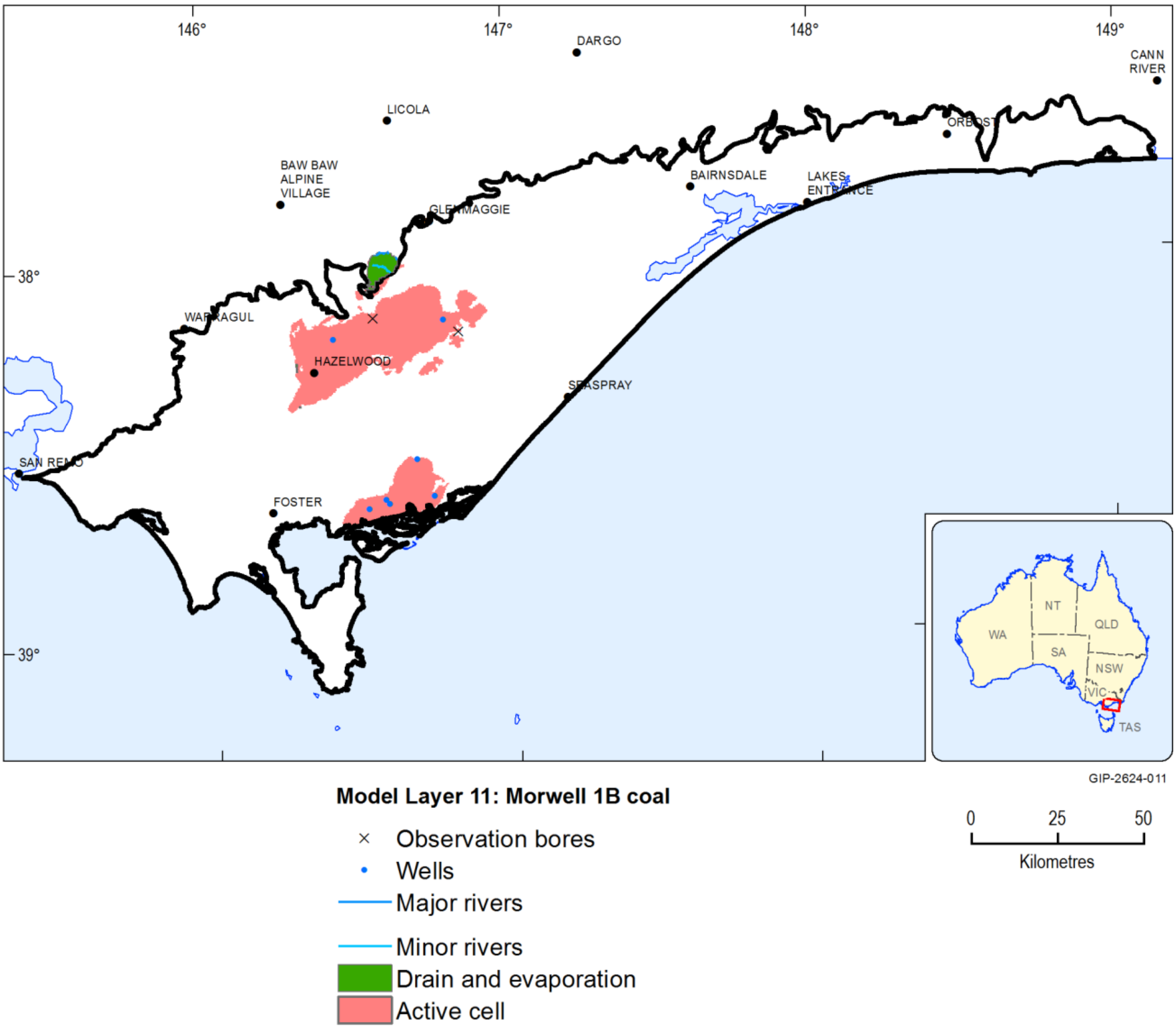


Figure 99 Boundary conditions of modelled layer 11

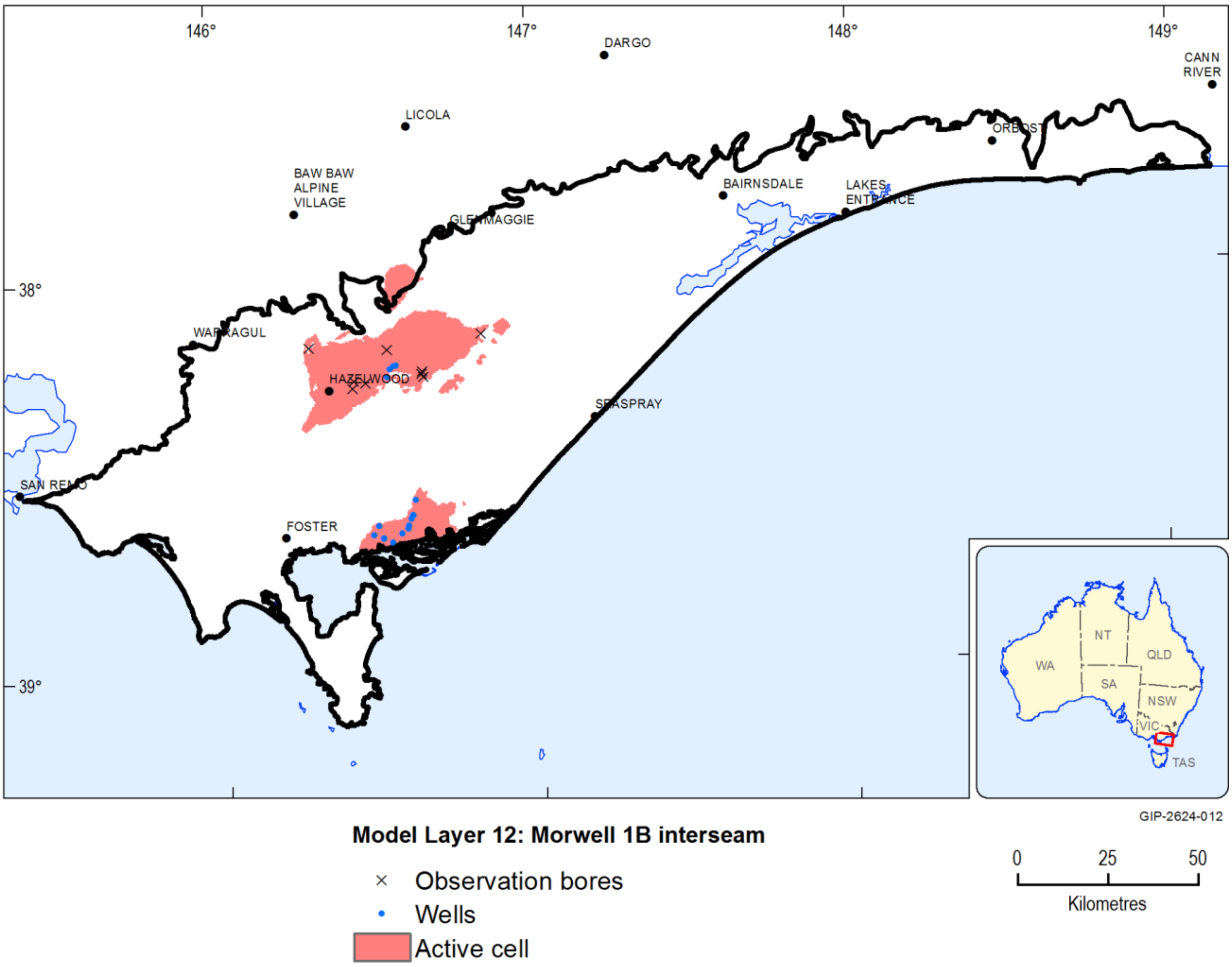


Figure 100 Boundary conditions of modelled layer 12

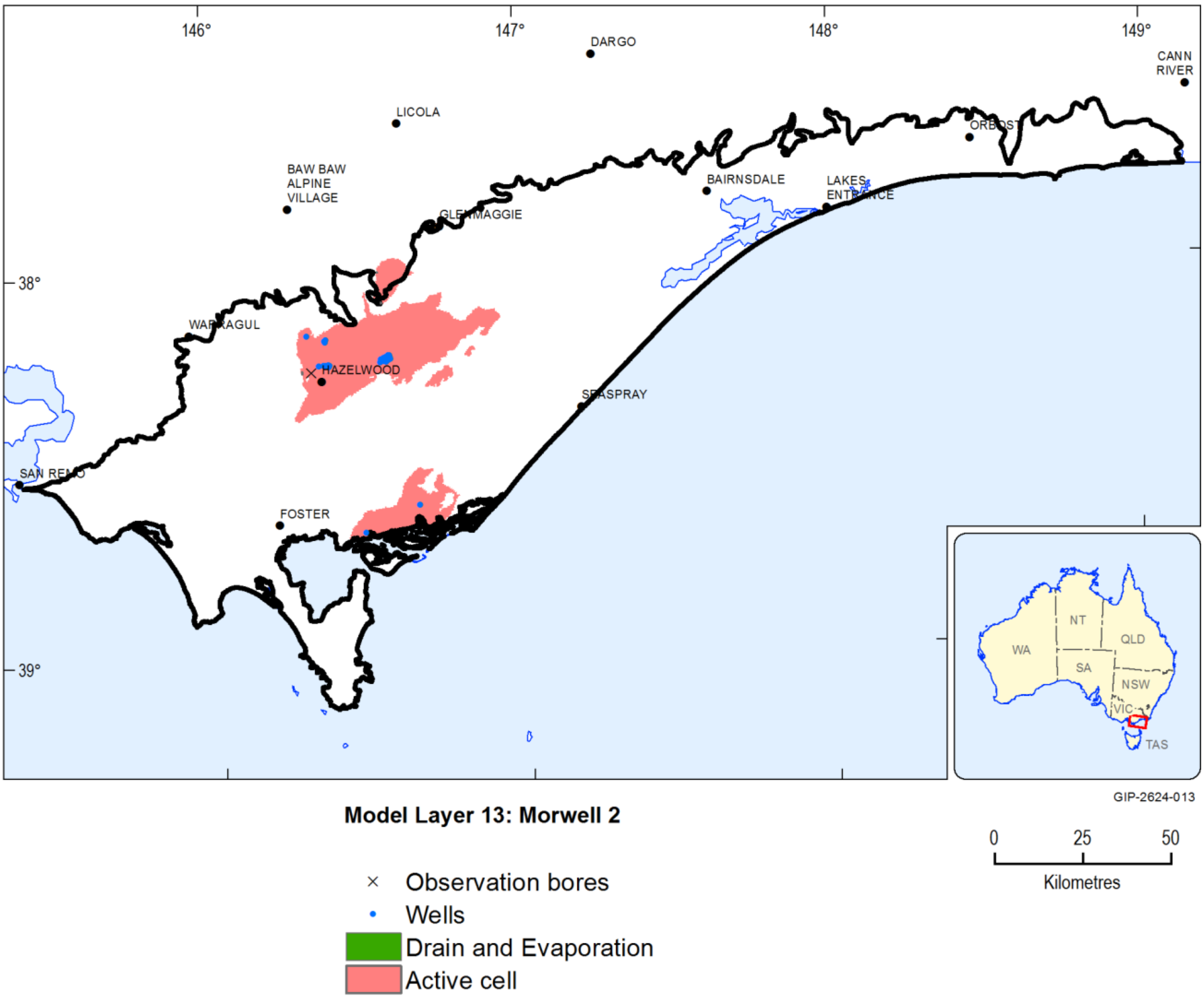


Figure 101 Boundary conditions of modelled layer 13

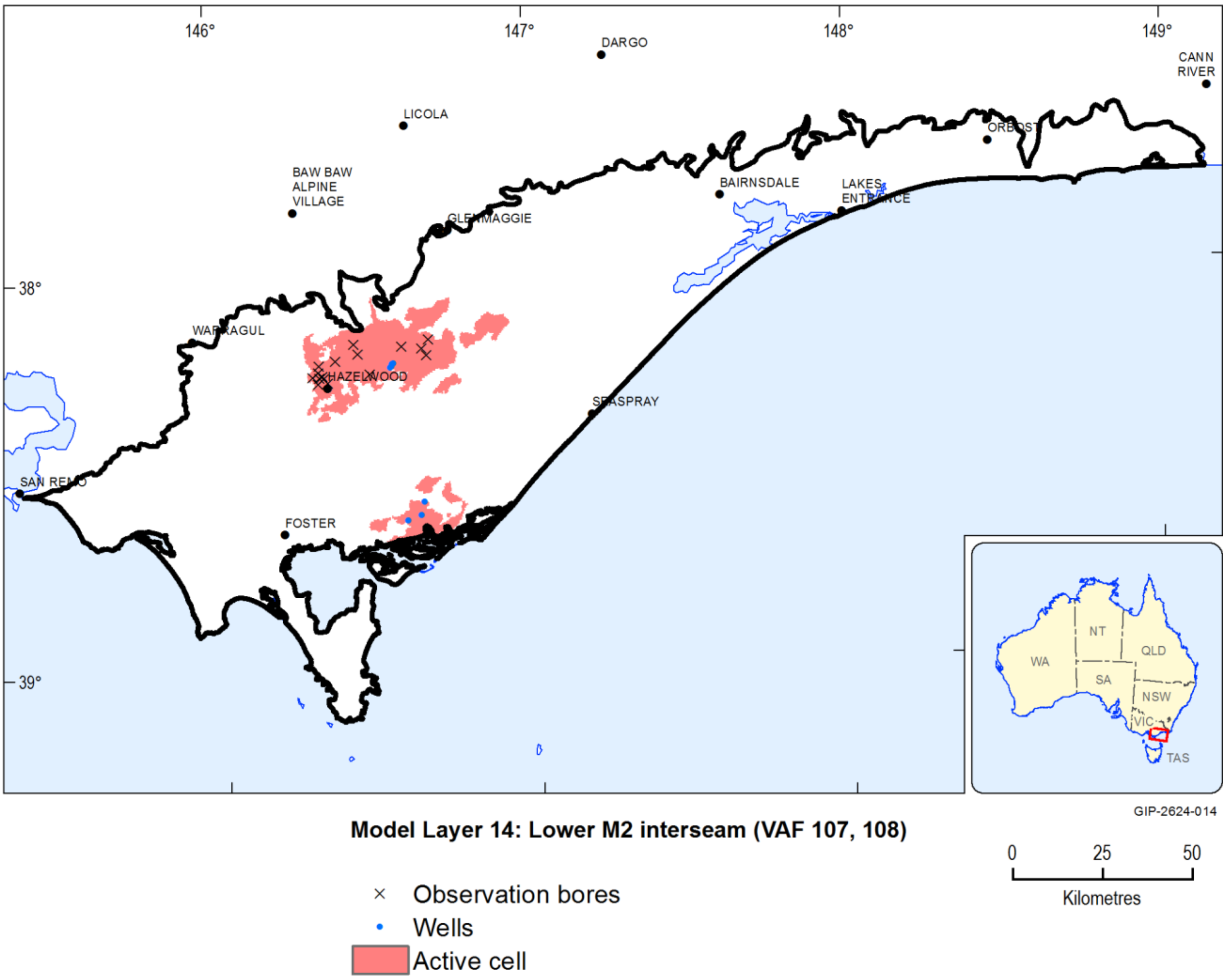


Figure 102 Boundary conditions of modelled layer 14

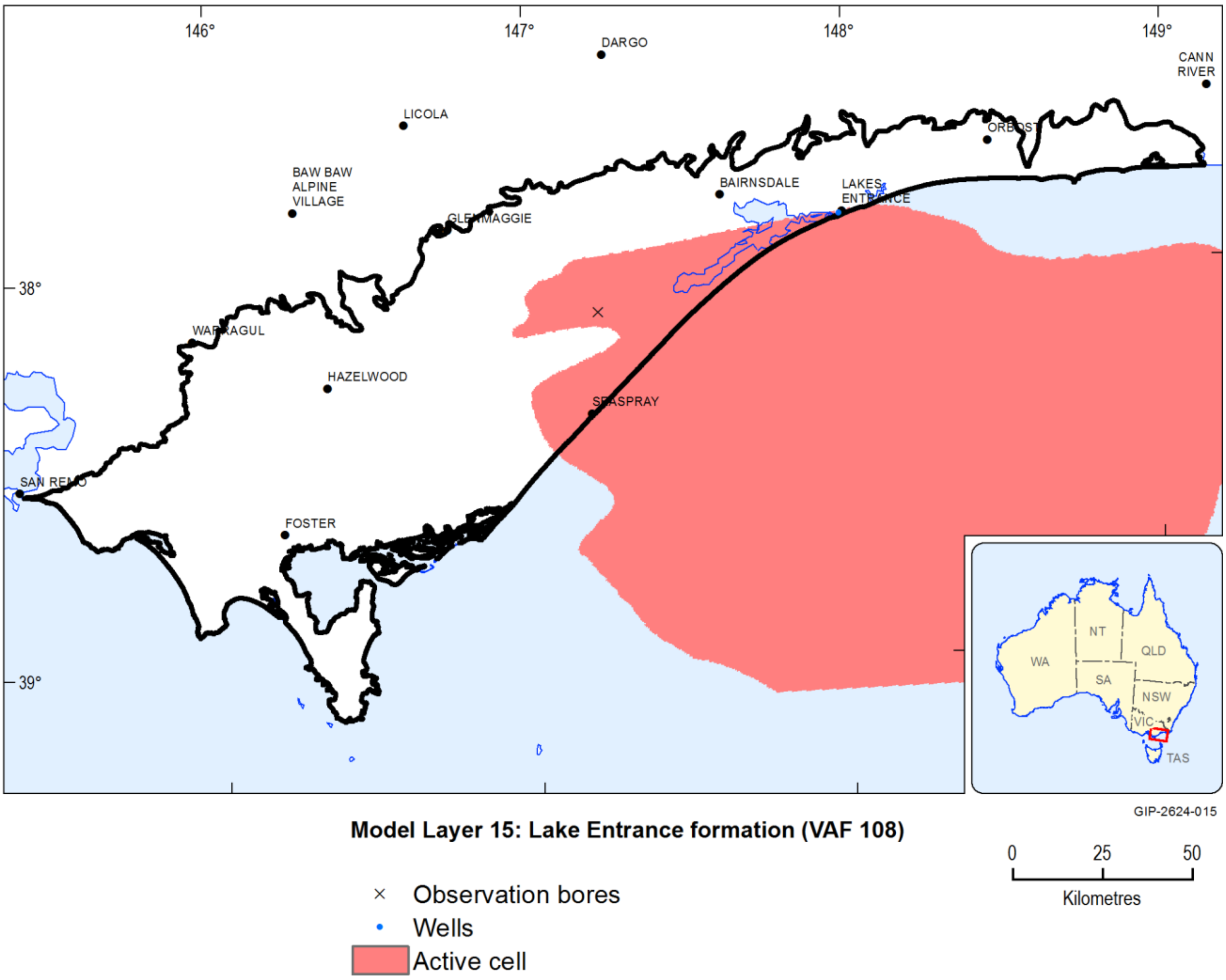


Figure 103 Boundary conditions of modelled layer 15

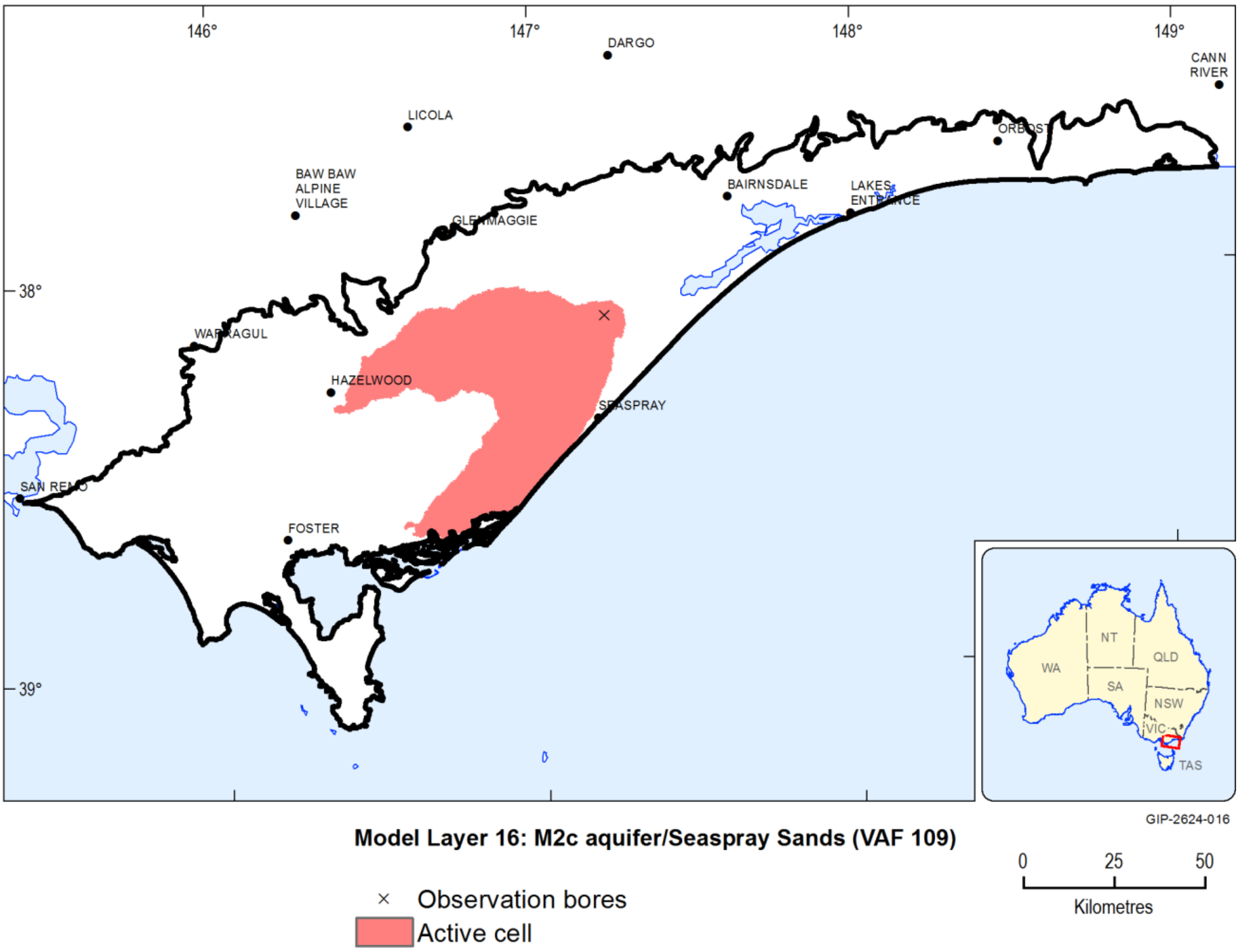


Figure 104 Boundary conditions of modelled layer 16

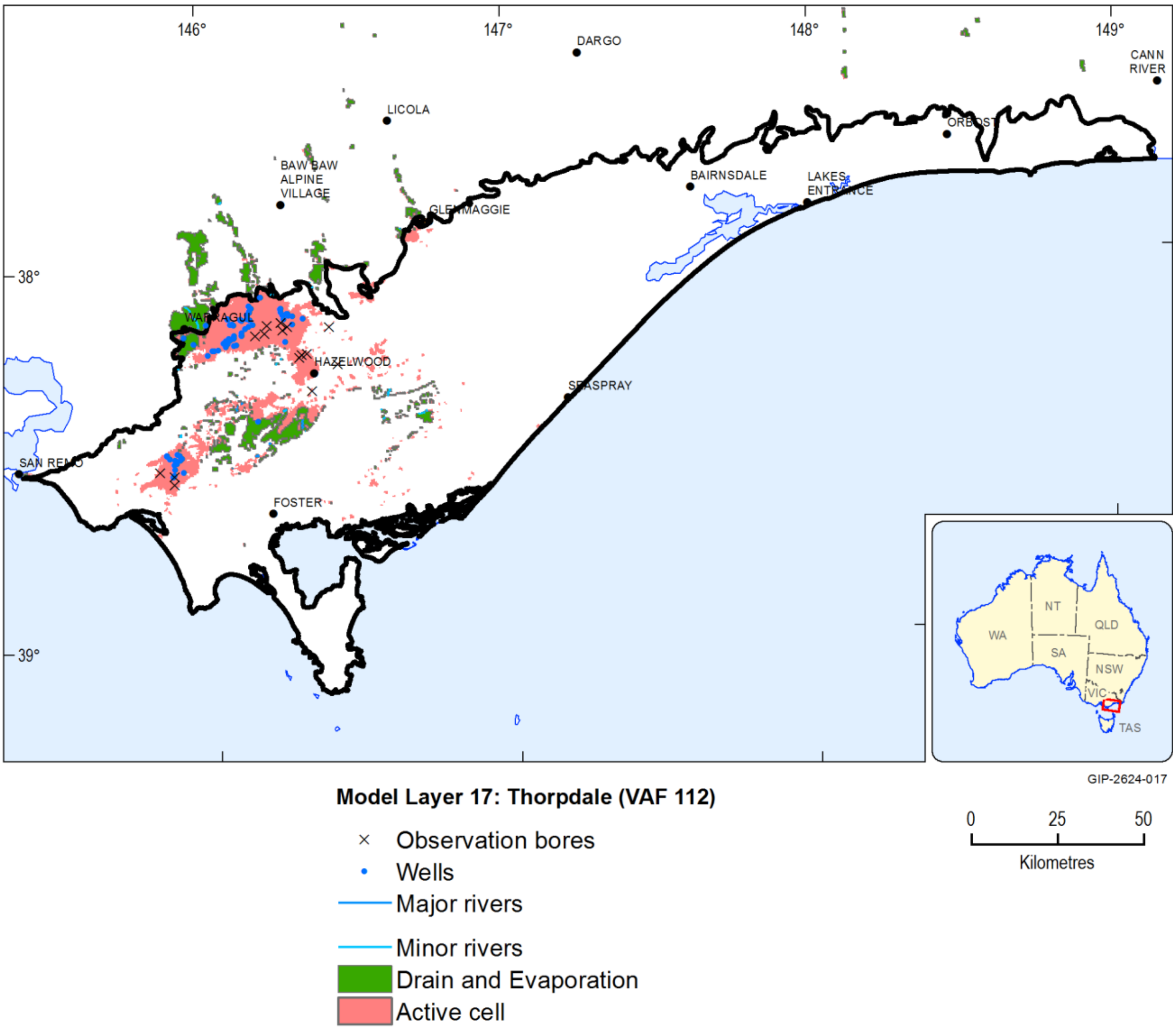


Figure 105 Boundary conditions of modelled layer 17

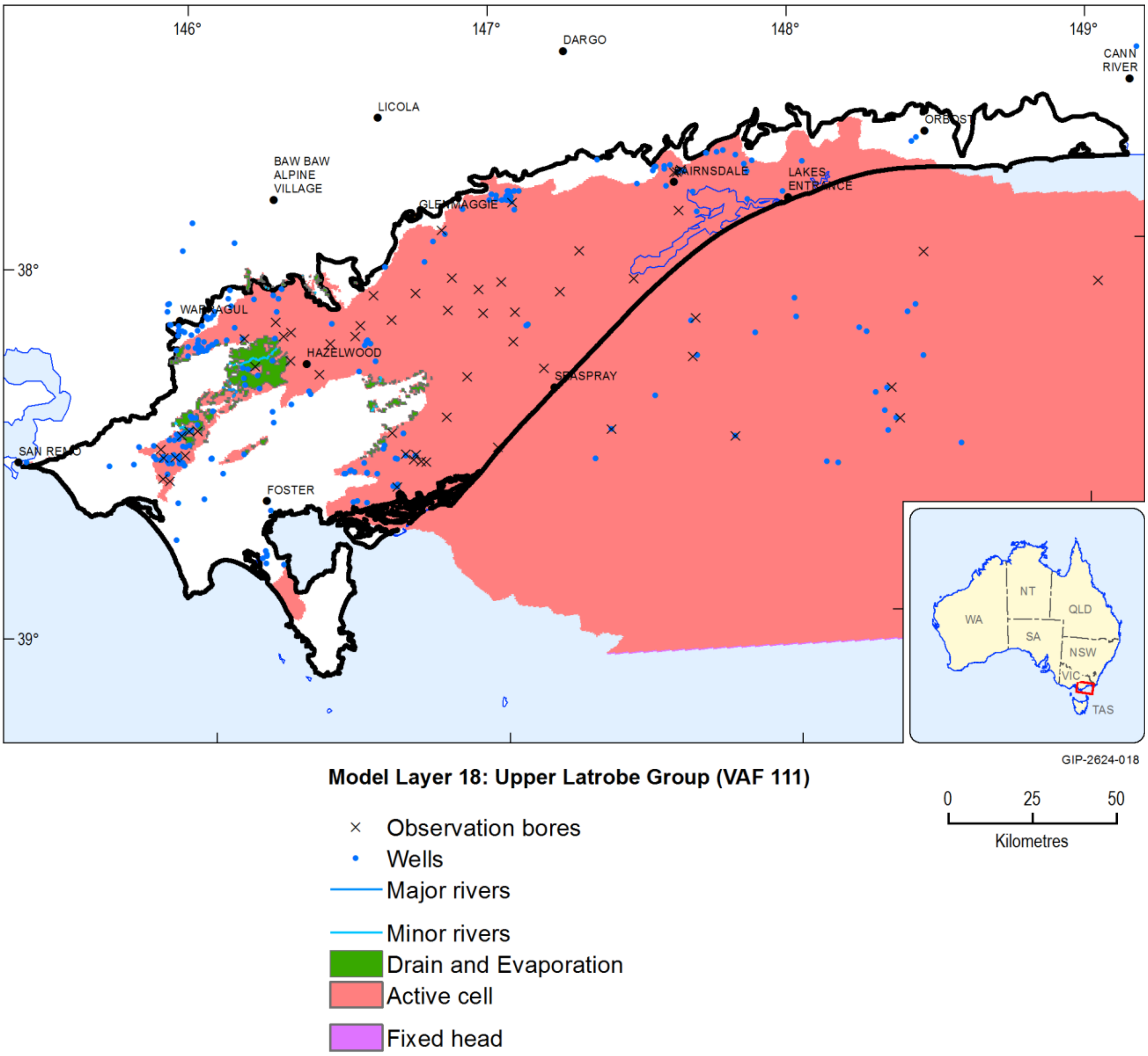


Figure 106 Boundary conditions of modelled layer 18

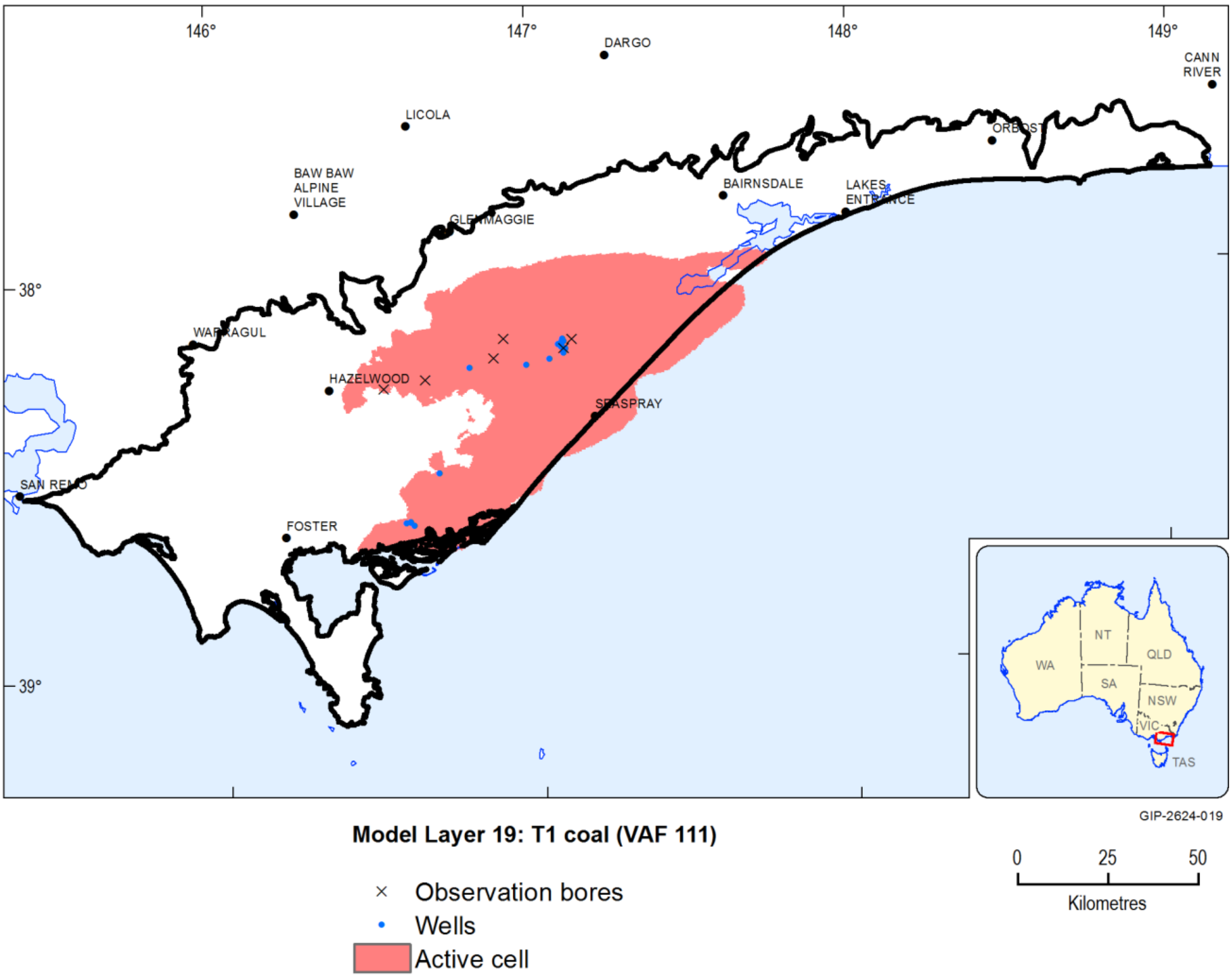


Figure 107 Boundary conditions of modelled layer 19

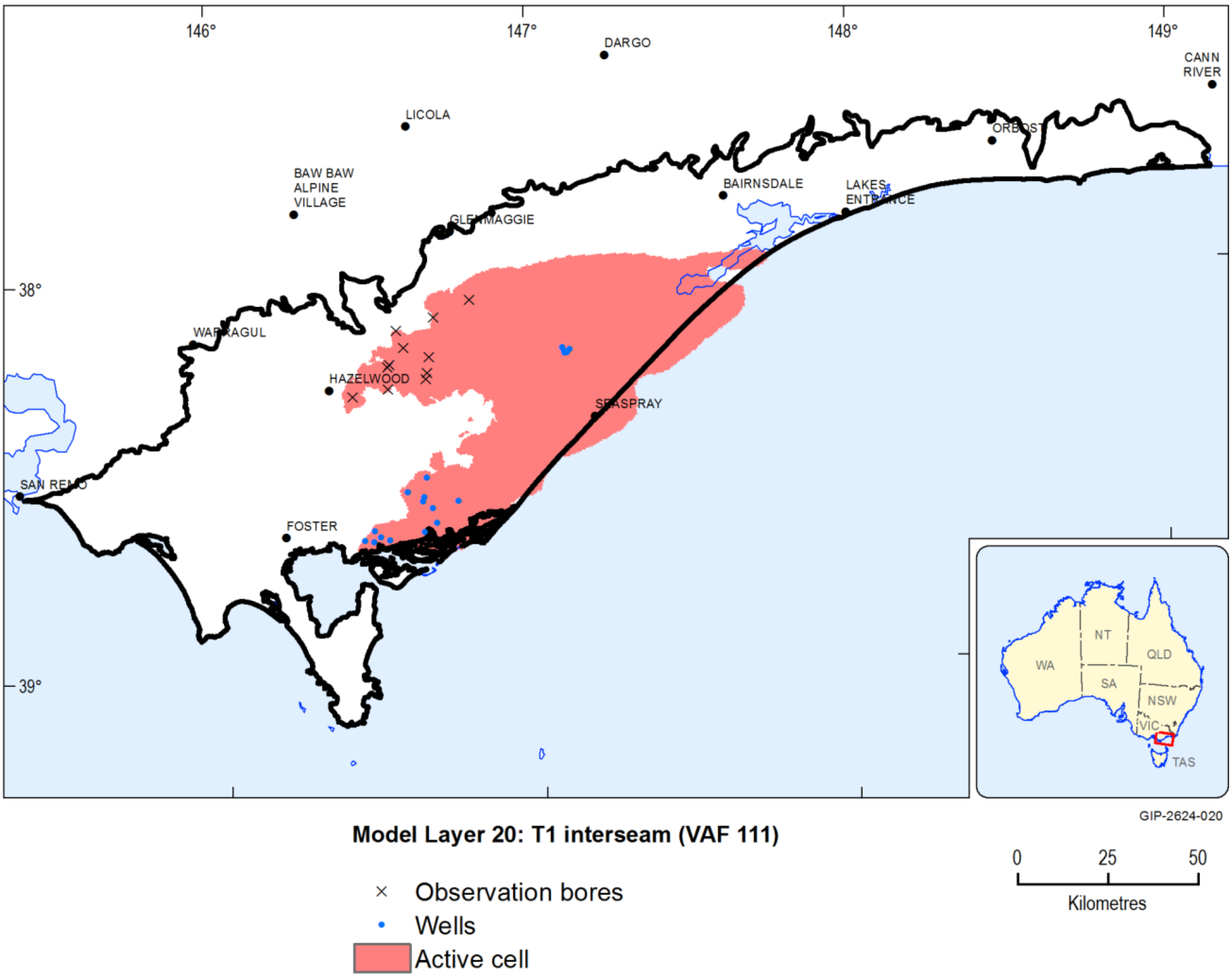


Figure 108 Boundary conditions of modelled layer 20

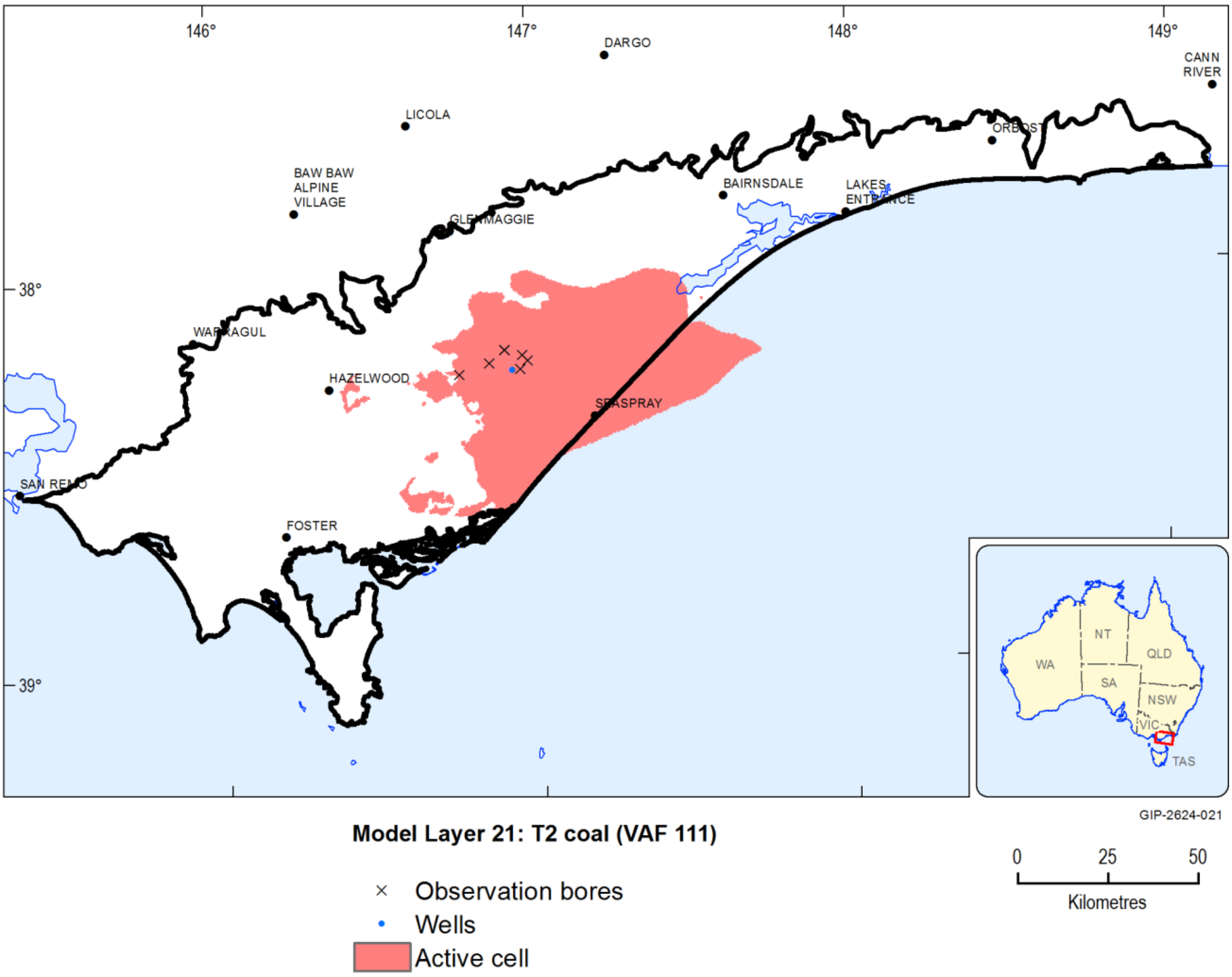


Figure 109 Boundary conditions of modelled layer 21

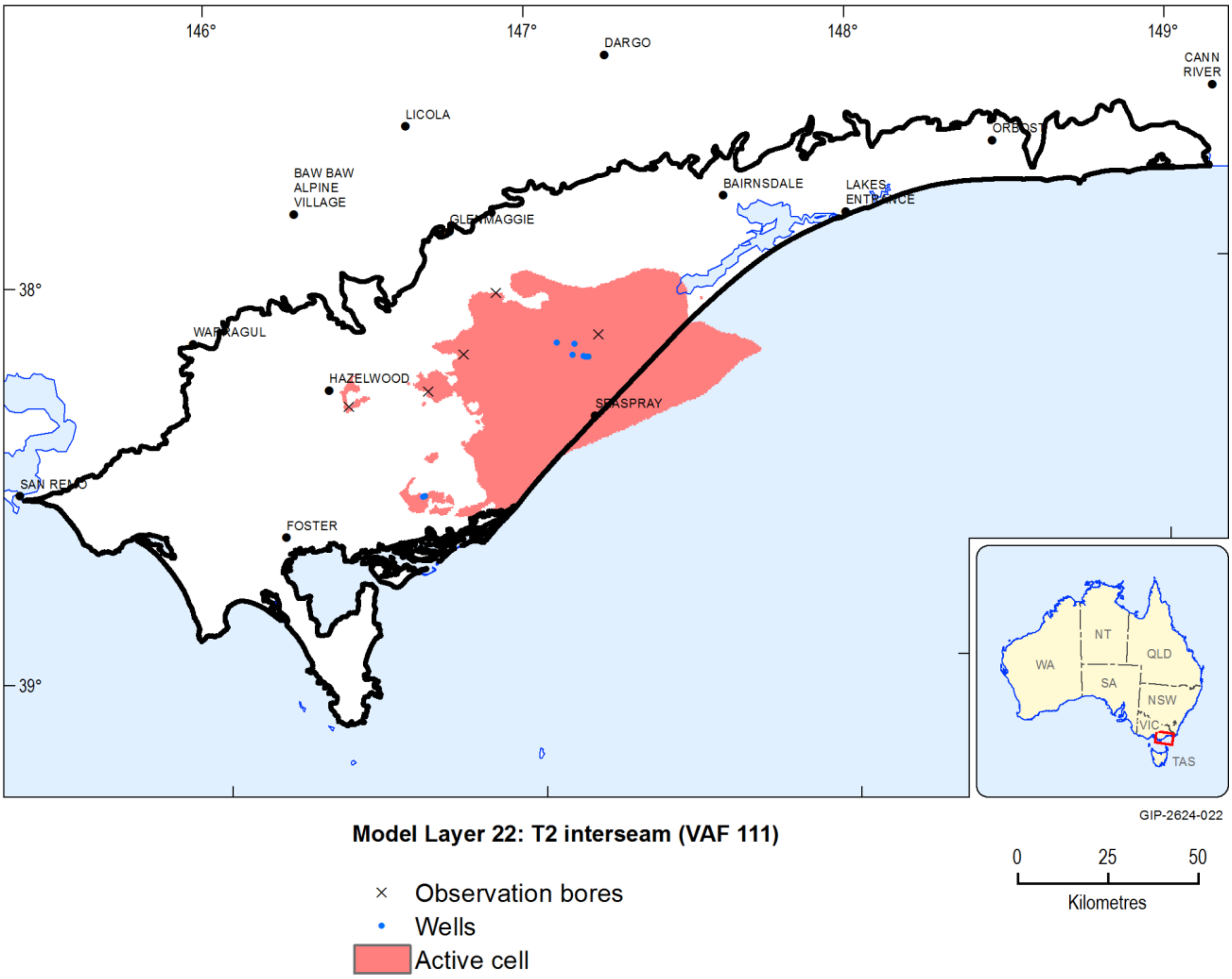


Figure 110 Boundary conditions of modelled layer 22

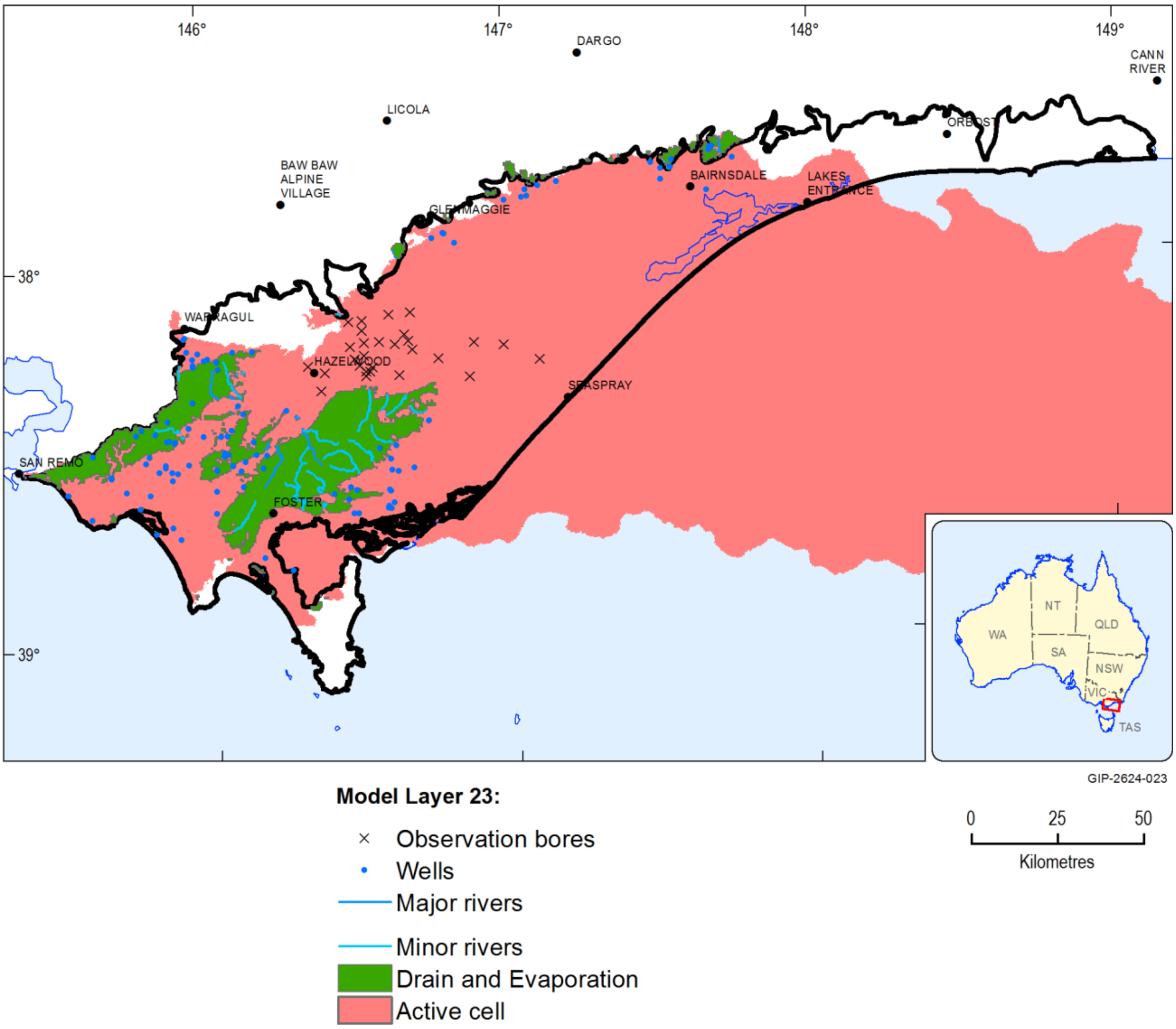


Figure 111 Boundary conditions of modelled layer 23

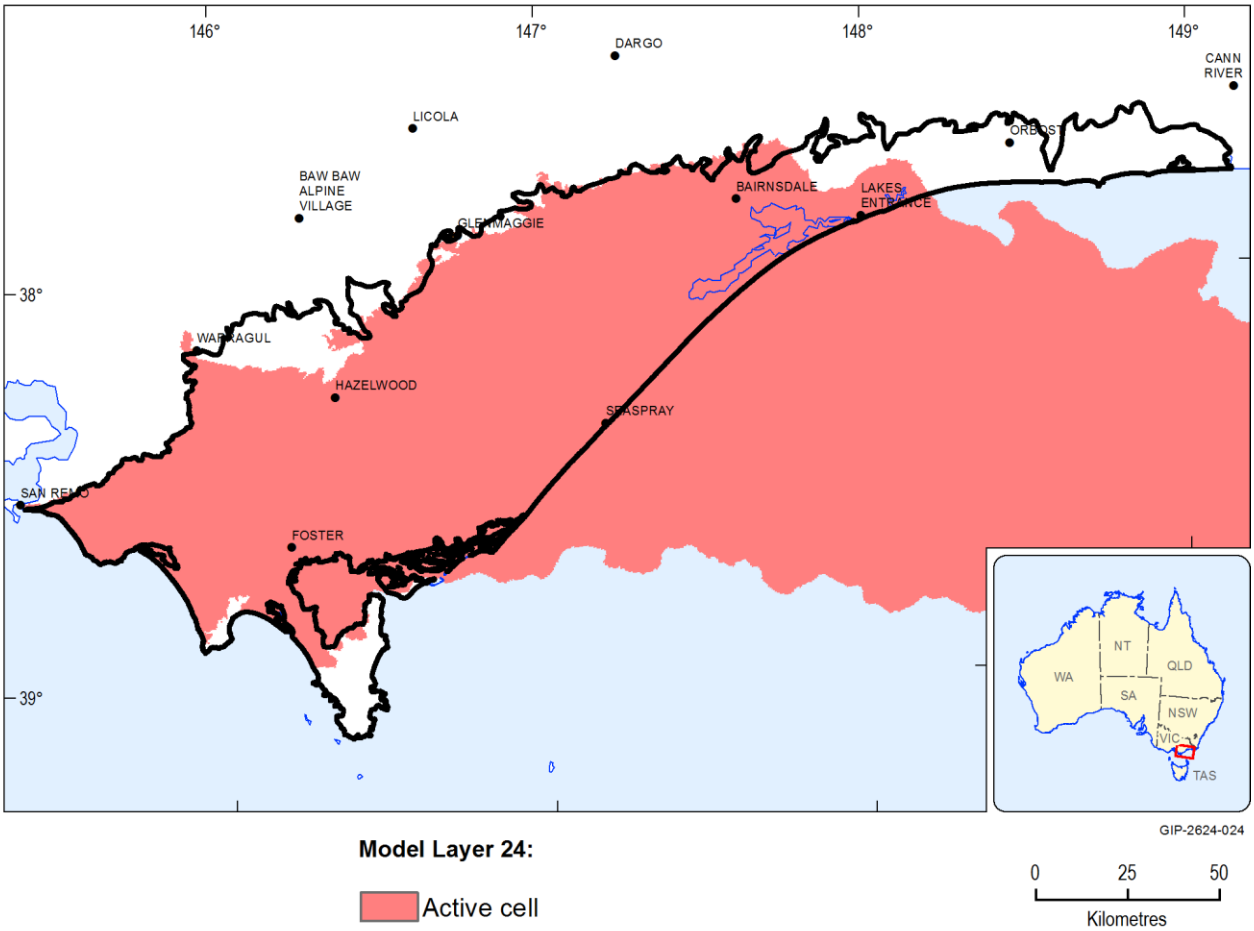


Figure 112 Boundary conditions of modelled layer 24

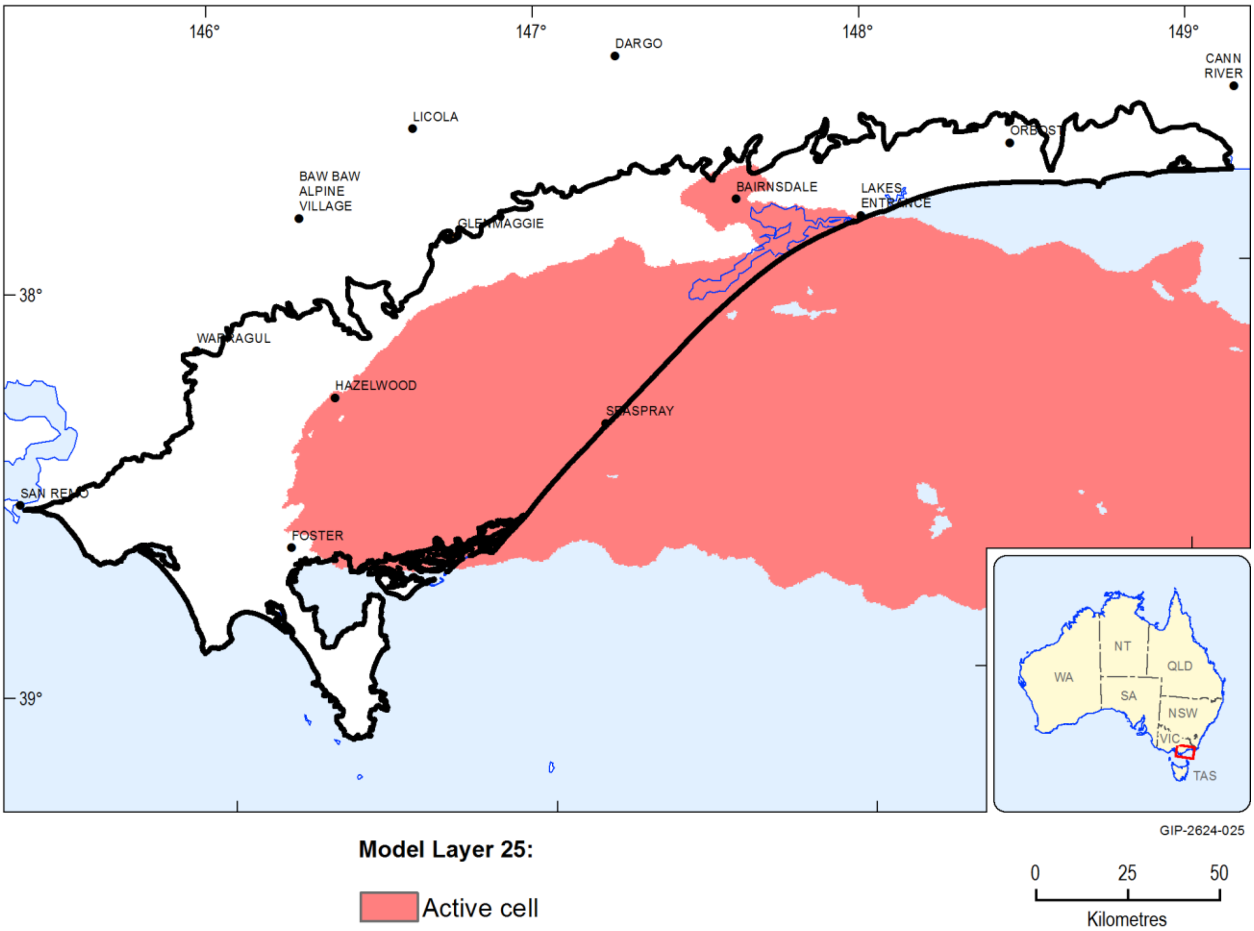


Figure 113 Boundary conditions of modelled layer 25

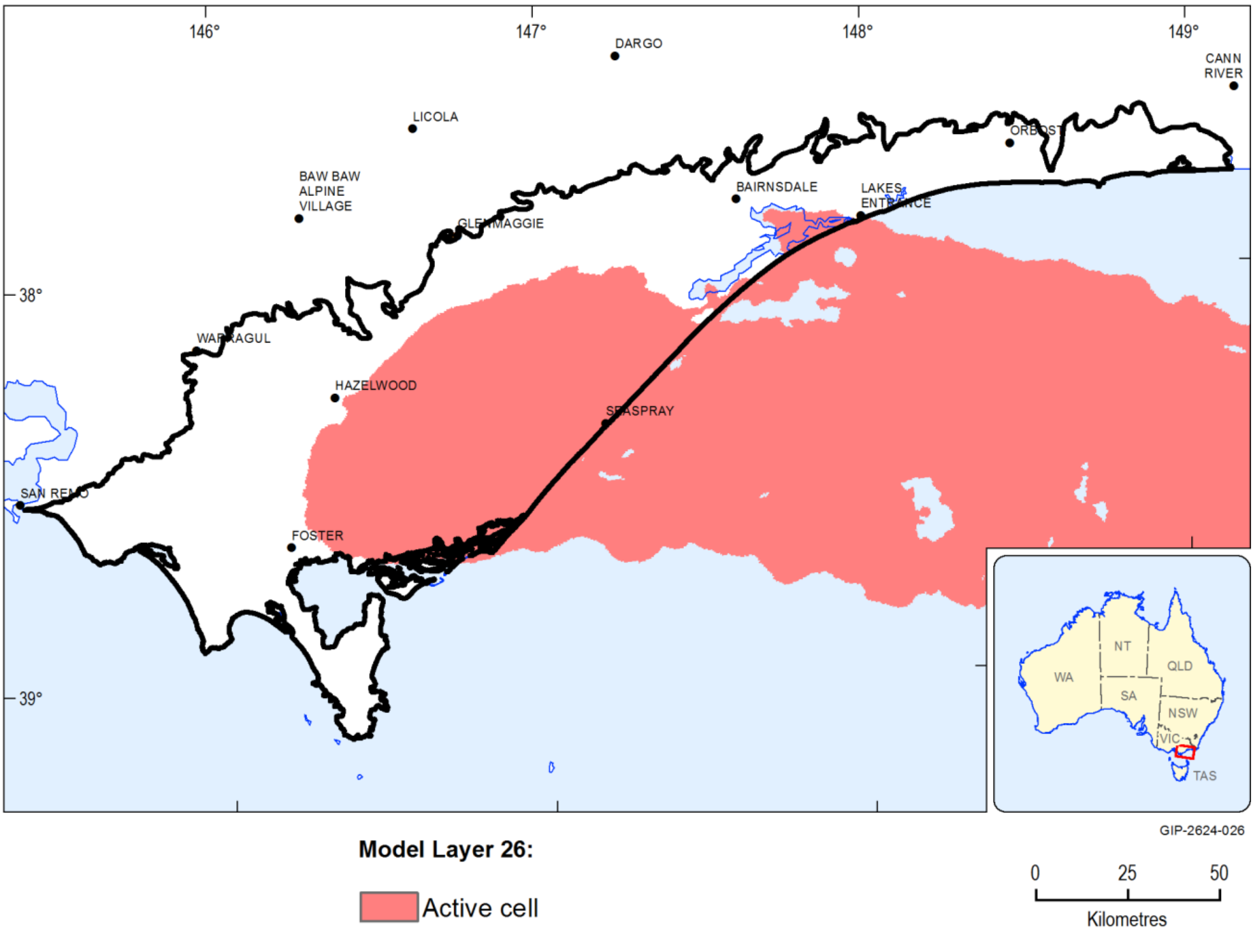


Figure 114 Boundary conditions of modelled layer 26

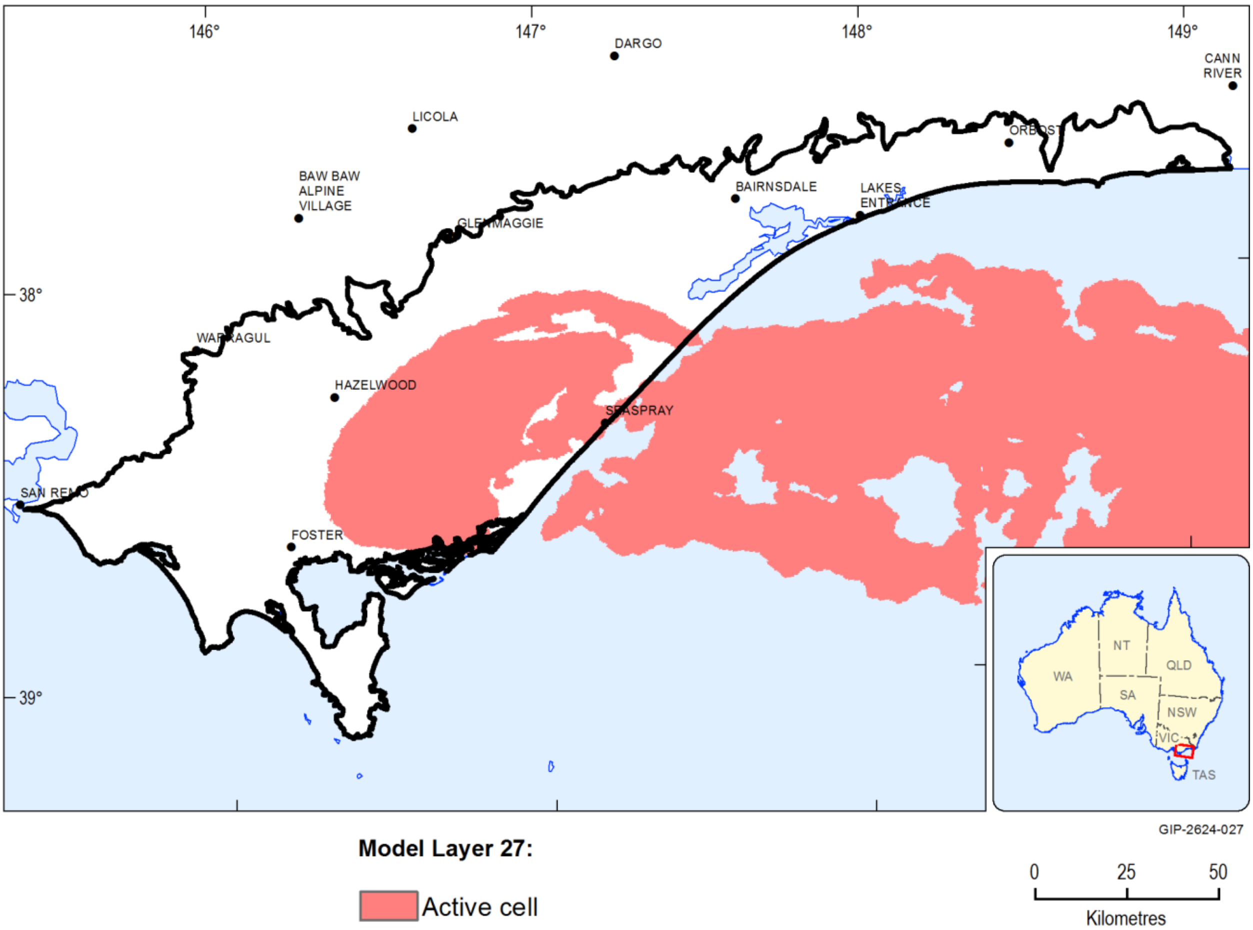


Figure 115 Boundary conditions of modelled layer 27

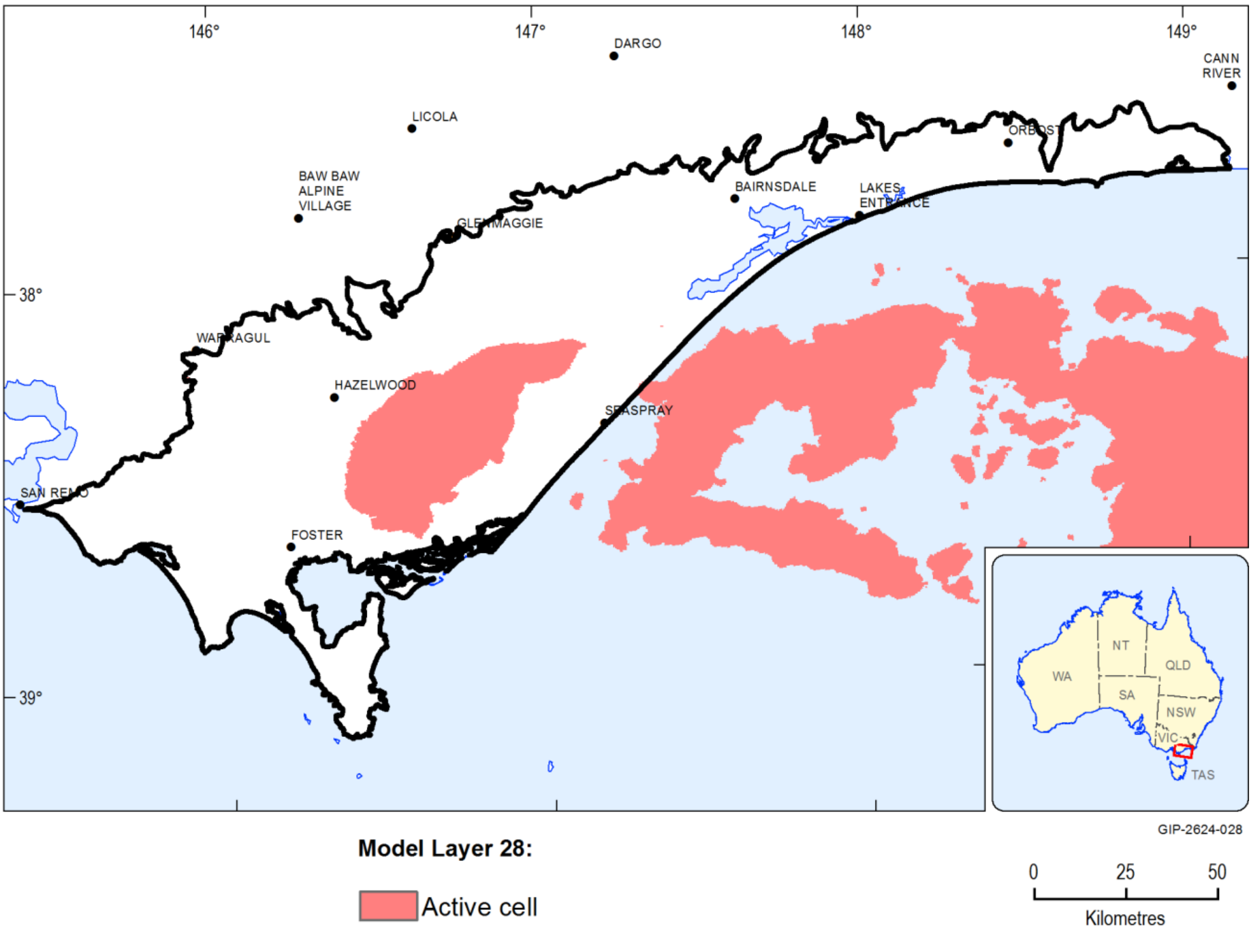


Figure 116 Boundary conditions of modelled layer 28

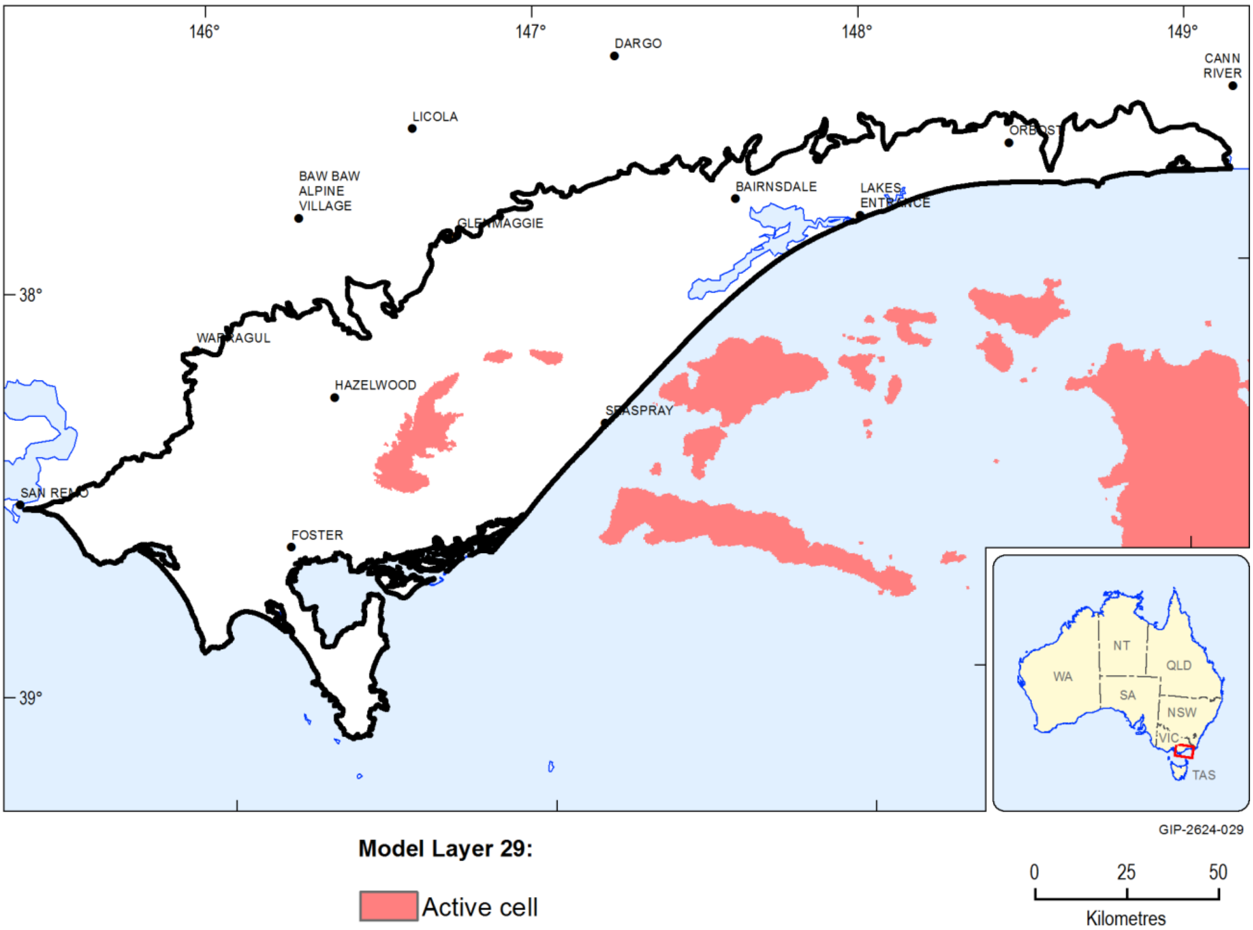


Figure 117 Boundary conditions of modelled layer 29

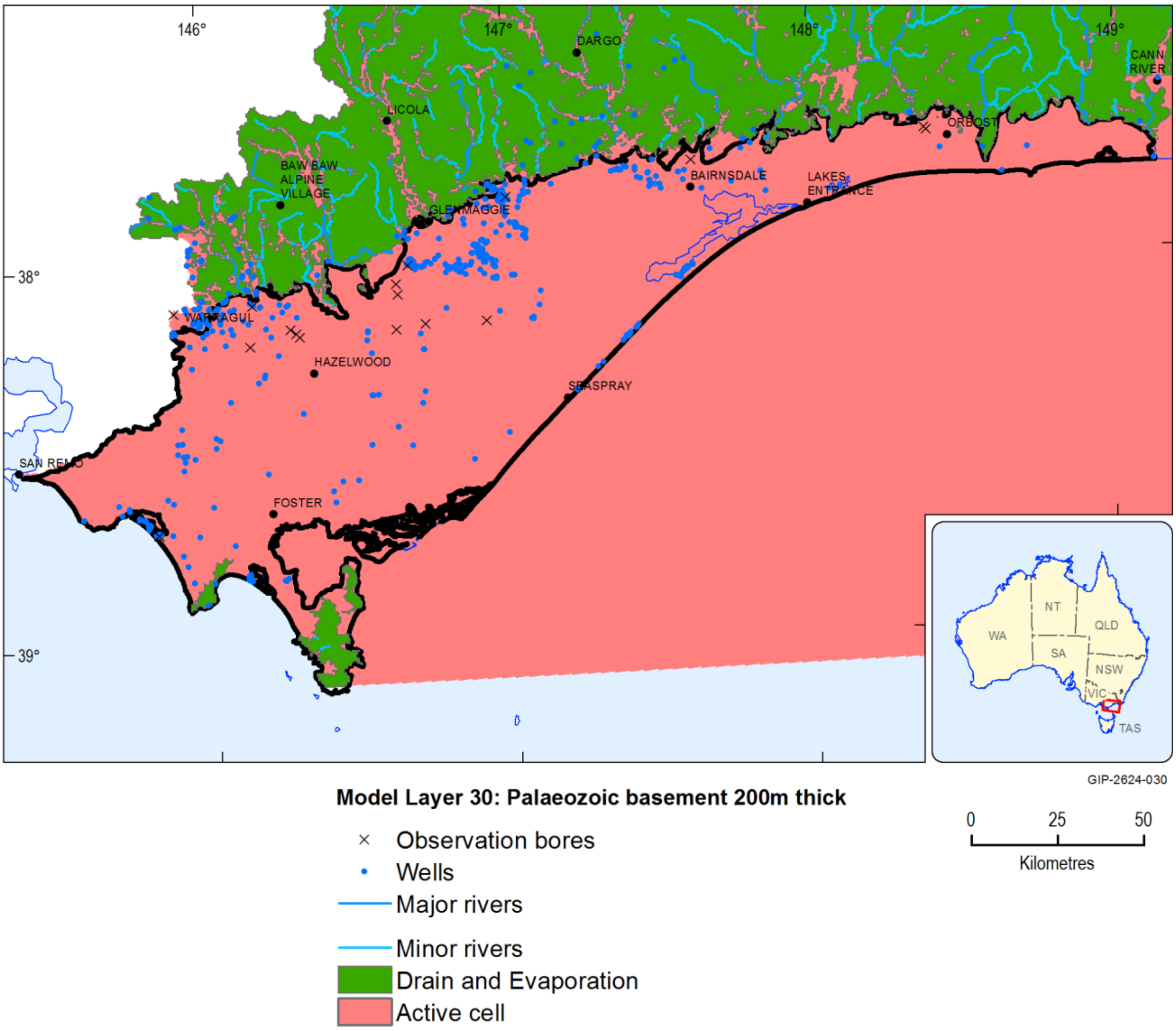


Figure 118 Boundary conditions of modelled layer 30

2.6.2.4.3 Allowance for temperature and density

The model does not explicitly simulate non-isothermal processes, density driven flows, contaminant flow or subsidence. As such solute transport and water quality has not been explicitly modelled. It is acknowledged that temperature variation over the depth range considered, both onshore and offshore, is large as are the offshore salinity variations. Density gradients offshore are known to significantly influence pressure distributions resulting in flows towards the shoreline that are difficult to approximate using a constant density model. There are limitations to ignoring density variations at the coast and off-shore but there was insufficient time to address the significance of these. However, the assumption of constant density is not considered to significantly compromise the onshore predictions of the shallow system response for the purpose of this study.

It is noteworthy that data used in CSIRO modelling that accounted for density (to assess potential for seawater intrusion) and temperature (due to geothermal resources in the basin) has been used in the calibration process. Specifically, the predevelopment and 2005 simulated potentiometric surfaces derived by CSIRO modelling for the Latrobe Group have been adjusted to remove the density and temperature impacts. These adjusted surfaces were then used in the calibration procedures. Given the limited available data this approach was deemed appropriate and pragmatic. Density head correction adjustments were also made to all groundwater observation bore data.

2.6.2.4.4 Allowance for faults

Geological faults and other geological discontinuities have not been explicitly modelled. Analysis of the stratigraphic data identified connection between the offshore and onshore units. Additionally, the properties were estimated to be continuous and not truncated. Faults were therefore considered to the extent that they were incorporated in the model geometry.

2.6.2.4.5 Allowance for flooding

Flooding contributes to episodic recharge and was considered in the Gippsland groundwater modelling study. For example, in early June 2012 much of Gippsland experienced heavy rainfall, causing flooding across a number of municipalities, including Latrobe, Wellington and East Gippsland. Hydrograph analysis revealed that groundwater levels responded to this event.

For this study flood data was sourced from the Victorian Flood Database and included information regarding the location and extent of a 1-in-100 year event (Figure 119) and historical flood events. Figure 120 shows the location and extent of recent major floods and

Table 9 presents the magnitude of each flooding event in the past 100 years (including area directly affected and duration).

Although damage caused by some recent flooding events (e.g. June 2012) to towns and communities was widespread in the Gippsland region, the areas directly affected by flooding were relatively small compared to the total area of the region. The extent of the 1-in-100 year flooding event only covers 4.8% of the total area of the Gippsland region. In the last 100 years, flooding events mainly occurred in small areas around the lower reaches of the Mitchell, Thomson, Latrobe and Snowy rivers. The area directly affected by flooding was generally less than 1% of the Gippsland region. The largest flood event occurred in June 2012 and covered 1.4% of the Gippsland region. Given the areas affected by historic flooding events were relatively small, it is believed that the impact of flooding on groundwater recharge is insignificant at the regional scale, but likely to be significant at the local scale.

By examining groundwater hydrographs across the Gippsland region, a noticeable impact of flooding on groundwater recharge is only evidenced in the shallow aquifer systems well connected to the lower reaches of the Thomson, Mitchell and Latrobe rivers. It was found that recharge spikes in groundwater hydrographs of some shallow bores near the rivers are aligned to high river flow events.

2.6.2.4.5 Allowance for flooding

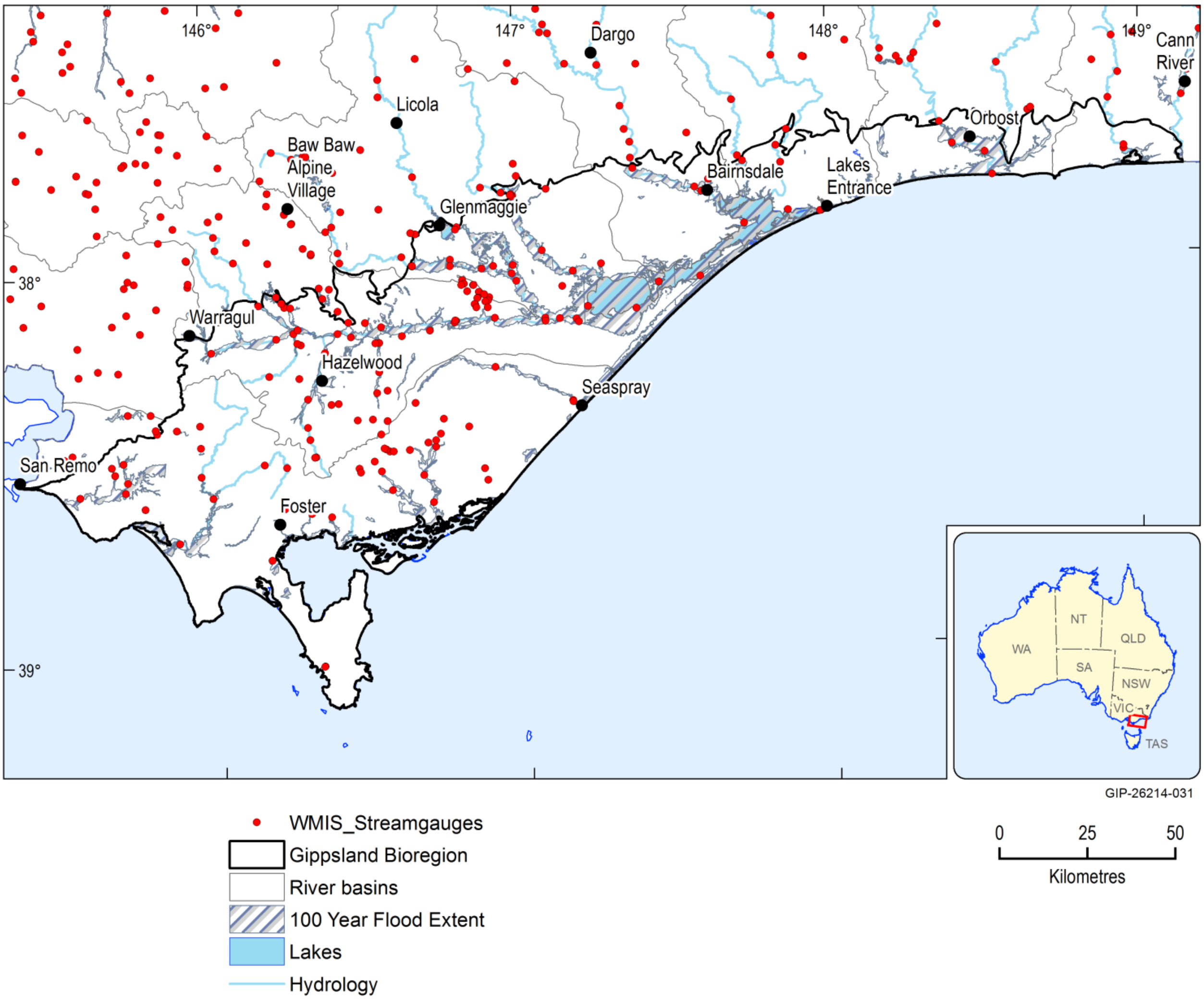


Figure 119 Location and extent of 1-in-100 year flooding events in the Gippsland region (source: Victorian Flood Database)

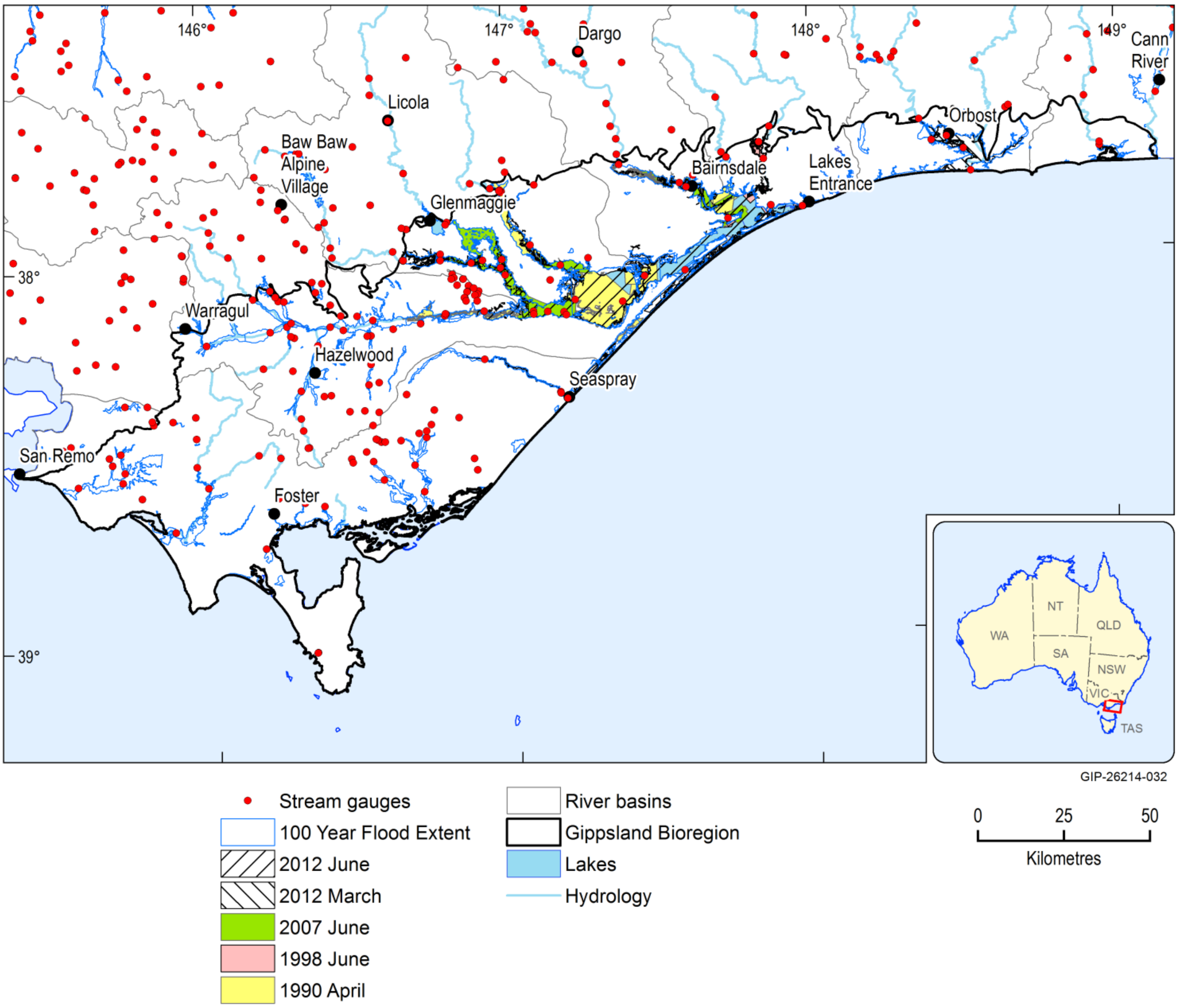


Figure 120 Location and extent of major recent flooding events (source: the Victorian Flood Database)

2.6.2.4.5 Allowance for flooding

Table 9 Extents of historical flood events (source: Victorian Flood Database)

Date	Duration (days)	Area affected (ha)	% of total catchment area
Jan-1919	Not known	2717	0.1
Jan-1920	Not known	1129	0.0
Oct-1923	Not known	208	0.0
Jan-1934	Not known	7527	0.2
Dec-1934	Not known	13361	0.4
May-1968	1	544	0.0
Jun-1969	1	644	0.0
Feb-1971	Not known	1666	0.0
Sep-1974	Not known	42	0.0
Jan-1977	Not known	11323	0.3
Jul-1977	3	20248	0.5
Jan-1978	Not known	2884	0.1
May-1978	5	14947	0.4
Jun-1978	5	12086	0.3
Jul-1978	1	3709	0.1
Jan-1985	Not known	740	0.0
Dec-1985	1	6427	0.2
Nov-1988	1	7061	0.2
Apr-1990	27	32563	0.9
Oct-1990	1	3278	0.1
Oct-1991	1	169	0.0
Sep-1993	16	2155	0.1
Jun-1998	3	6364	0.2
Nov-1998	1	949	0.0
Jun-2007	4	23308	0.6
Jul-2011	Not known	36	0.0
Mar-2012	8	9023	0.2
Jun-2012	3	54912	1.4
1-in-100 year extent	N/A	181490	4.8

Table 10 Modelled flood extents and dates

Flood event date	Recorded dates
2012June_ext	6/6, 7/6
2012March_ext	3/3, 9/3,10/3
2011July_ext	1/7
2007June	26/6, 29/9
1998Nov_ext	14/11
1998June_ext	23/6, 24/6, 25/6
1993Sep_ext	1/9, 14/9, 15/9, 16/9
1991Oct_ext	3/10
1990Oct_ext	11/10
1990April_ext	1/4, 22/4, 23/4, 25/4, 27/4
1988Nov_ext	18/11
1985Dec_ext	12/12
1985Jan_ext	1/1
1978July_ext	9/7
1978June_ext	1/6, 4/6, 5/6
1978May_ext	21/5, 22/5, 25/5
1978Jan_ext	1/1
1977July_ext	1/7, 27/7
1977Jan_ext	1/1
1974Sep_ext	1/9
1971Feb_ext	½
1969June_ext	4/6

2.6.2.4.6 Model recharge

Dryland rainfall recharge, irrigation recharge and flood induced episodic recharge have been incorporated into the groundwater model based on predictions derived using the Catchment Analysis Tool (CAT) unsaturated catchment model (Beverly et al., 2005; Beverly, 2009a). Recharge derived from irrigation has been estimated using management scripts representing irrigation practices adopted by each irrigated agricultural industry. These management scripts are assigned to irrigated land units within the land use layer and describe irrigation triggers, irrigation application volumes and frequency of irrigation events. Flood induced episodic recharge has been simulated by maintaining saturation in the surface soil layer in all regions within mapped flood extents. The duration of inundation was arbitrarily set as 5 days, unless specific information to the contrary was available. The spatially averaged annual recharge is summarised in Table 11.

Table 11 Spatially averaged groundwater potential evapotranspiration and recharge for each modelled time period

Stress period	Period	Time step (ts)	Days per timestep	Rain (mm/ts)	G'water Evap'n (mm/ts)	Recharge (mm/ts)	Rech/Rain (%)
1	01/01/1971 – 31/12/1971	365	365	1022	783	65	6.31
2	01/01/1972 – 31/12/1972	366	731	626	619	20	3.14
3	01/01/1973 – 31/12/1973	365	1096	1035	644	76	7.37
4	01/01/1974 – 31/12/1974	365	1461	1353	678	173	12.78
5	01/01/1975 – 31/12/1975	365	1826	1064	682	108	10.18
6	01/01/1976 – 31/12/1976	366	2192	914	641	78	8.49
7	01/01/1977 – 31/12/1977	365	2557	840	639	78	9.28
8	01/01/1978 – 31/12/1978	365	2922	1378	639	166	12.02
9	01/01/1979 – 31/12/1979	365	3287	677	615	49	7.29
10	01/01/1980 – 31/12/1980	366	3653	879	662	50	5.72
11	01/01/1981 – 31/12/1981	365	4018	945	671	71	7.51
12	01/01/1982 – 31/12/1982	365	4383	671	616	29	4.38
13	01/01/1983 – 31/12/1983	365	4748	1021	569	102	10.04
14	01/01/1984 – 31/12/1984	366	5114	965	649	91	9.39
15	01/01/1985 – 31/12/1985	365	5479	1143	613	113	9.85
16	01/01/1986 – 31/12/1986	365	5844	782	626	75	9.55
17	01/01/1987 – 31/12/1987	365	6209	828	631	59	7.13
18	01/01/1988 – 31/12/1988	366	6575	995	626	72	7.25
19	01/01/1989 – 31/12/1989	365	6940	1031	655	122	11.81
20	01/01/1990 – 31/03/1990	90	7030	145	179	3	1.77
21	01/04/1990 – 30/06/1990	91	7121	283	96	19	6.86
22	01/07/1990 – 30/09/1990	92	7213	308	114	50	16.25
23	01/10/1990 – 31/12/1990	92	7305	238	262	22	9.15
24	01/01/1991 – 31/03/1991	90	7395	199	194	4	1.90
25	01/04/1991 – 30/06/1991	91	7486	243	92	12	4.92
26	01/07/1991 – 30/09/1991	92	7578	359	118	64	17.82

Stress period	Period	Time step (ts)	Days per timestep	Rain (mm/ts)	G'water Evap'n (mm/ts)	Recharge (mm/ts)	Rech/Rain (%)
27	01/10/1991 – 31/12/1991	92	7670	165	241	7	4.53
28	01/01/1992 – 31/03/1992	91	7761	193	191	6	3.01
29	01/04/1992 – 30/06/1992	91	7852	216	76	12	5.77
30	01/07/1992 – 30/09/1992	92	7944	303	111	40	13.34
31	01/10/1992 – 31/12/1992	92	8036	377	231	47	12.50
32	01/01/1993 – 31/03/1993	90	8126	248	217	17	6.89
33	01/04/1993 – 30/06/1993	91	8217	125	94	11	9.11
34	01/07/1993 – 30/09/1993	92	8309	339	112	49	14.55
35	0110/1993 – 31/12/1993	92	8401	304	247	31	10.14
36	01/01/1994 – 31/03/1994	90	8491	266	213	15	5.77
37	01/04/1994 – 30/06/1994	91	8582	192	107	14	7.45
38	01/07/1994 – 30/09/1994	92	8674	143	111	13	9.14
39	01/10/1994 – 31/12/1994	92	8766	243	249	16	6.59
40	01/01/1995 – 31/03/1995	90	8856	207	202	5	2.32
41	01/04/1995 – 30/06/1995	91	8947	252	87	25	9.94
42	01/07/1995 – 30/09/1995	92	9039	203	121	26	12.65
43	0110/1995 – 31/12/1995	92	9131	378	234	38	10.11
44	01/01/1996 – 31/03/1996	91	9222	230	220	10	4.50
45	01/04/1996 – 30/06/1996	91	9313	191	92	18	9.45
46	01/07/1996 – 30/09/1996	92	9405	304	122	45	14.71
47	01/10/1996 – 31/12/1996	92	9497	211	246	13	6.08
48	01/01/1997 – 31/03/1997	90	9587	141	178	3	1.97
49	01/04/1997 – 30/06/1997	91	9678	174	73	5	2.75
50	01/07/1997 – 30/09/1997	92	9770	148	113	14	9.68
51	01/10/1997 – 31/12/1997	92	9862	158	223	3	1.96
52	01/01/1998 – 31/03/1998	90	9952	131	143	1	0.73
53	01/04/1998 – 30/06/1998	91	10043	295	69	10	3.32
54	01/07/1998 – 30/09/1998	92	10135	196	111	26	13.50
55	01/10/1998 – 31/12/1998	92	10227	317	264	17	5.44

Stress period	Period	Time step (ts)	Days per timestep	Rain (mm/ts)	G'water Evap'n (mm/ts)	Recharge (mm/ts)	Rech/Rain (%)
56	01/01/1999 – 31/03/1999	90	10317	210	219	5	2.36
57	01/04/1999 – 30/06/1999	91	10408	156	91	9	5.99
58	01/07/1999 – 30/09/1999	92	10500	164	113	17	10.26
59	0110/1999 – 31/12/1999	92	10592	203	207	6	2.78
60	01/01/2000 – 31/03/2000	91	10683	168	188	3	1.84
61	01/04/2000 – 30/06/2000	91	10774	248	89	17	6.67
62	01/07/2000 – 30/09/2000	92	10866	235	112	29	12.26
63	01/10/2000 – 31/12/2000	92	10958	211	237	21	9.83
64	01/01/2001 – 31/03/2001	90	11048	199	179	3	1.58
65	01/04/2001 – 30/06/2001	91	11139	217	90	16	7.53
66	01/07/2001 – 30/09/2001	92	11231	285	113	42	14.73
67	01/10/2001 – 31/12/2001	92	11323	309	237	29	9.26
68	01/01/2002 – 31/03/2002	90	11413	216	205	7	3.17
69	01/04/2002 – 30/06/2002	91	11504	267	105	24	8.81
70	01/07/2002 – 30/09/2002	92	11596	145	128	17	11.73
71	01/10/2002 – 31/12/2002	92	11688	156	231	3	2.14
72	01/01/2003 – 31/03/2003	90	11778	104	121	0	0.45
73	01/04/2003 – 30/06/2003	91	11869	169	93	5	2.68
74	01/07/2003 – 30/09/2003	92	11961	228	130	22	9.45
75	01/10/2003 – 31/12/2003	92	12053	244	236	14	5.78
76	01/01/2004 – 31/03/2004	91	12144	111	143	2	1.40
77	01/04/2004 – 30/06/2004	91	12235	229	86	11	4.69
78	01/07/2004 – 30/09/2004	92	12327	220	119	22	10.13
79	01/10/2004 – 31/12/2004	92	12419	262	252	16	6.05
80	01/01/2005 – 3103/2005	90	12509	223	203	7	2.98
81	01/04/2005 – 30/06/2005	91	12600	116	86	3	2.74
82	01/07/2005 – 30/09/2005	92	12692	298	115	29	9.63
83	01/10/2005 – 31/12/2005	92	12784	223	266	10	4.48
84	01/01/2006 – 31/03/2006	90	12874	114	161	1	0.98

Stress period	Period	Time step (ts)	Days per timestep	Rain (mm/ts)	G'water Evap'n (mm/ts)	Recharge (mm/ts)	Rech/Rain (%)
85	01/04/2006 – 30/06/2006	91	12965	239	86	12	5.08
86	01/07/2006 – 30/09/2006	92	13057	174	123	13	7.38
87	01/10/2006 – 31/12/2006	92	13149	86	186	1	1.23
88	01/01/2007 – 31/03/2007	90	13239	190	157	1	0.37
89	01/04/2007 – 30/06/2007	91	13330	326	99	14	4.18
90	01/07/2007 – 30/09/2007	92	13422	188	126	33	17.44
91	01/10/2007 – 31/12/2007	92	13514	251	254	11	4.56
92	01/01/2008 – 31/03/2008	91	13605	172	193	4	2.11
93	01/04/2008 – 30/06/2008	91	13696	106	70	4	3.32
94	01/07/2008 – 30/09/2008	92	13788	199	117	18	8.82
95	01/10/2008 – 31/12/2008	92	13880	280	223	9	3.38
96	01/01/2009 – 31/03/2009	90	13970	81	154	2	2.10
97	01/04/2009 – 30/06/2009	91	14061	132	73	4	2.82
98	01/07/2009 – 30/09/2009	92	14153	252	133	21	8.18
99	01/10/2009 – 31/12/2009	92	14245	225	244	13	5.85
100	01/01/2010 – 31/03/2010	90	14335	251	195	6	2.35
101	01/04/2010 – 30/06/2010	91	14426	197	90	15	7.76
102	01/07/2010 – 30/09/2010	92	14518	205	106	30	14.53
103	01/10/2010 – 31/12/2010	92	14610	314	240	22	6.93
104	01/01/2011 – 31/03/2011	90	14700	293	198	18	6.18
105	01/04/2011 – 30/06/2011	91	14791	232	88	30	12.87
106	01/07/2011 – 30/09/2011	92	14883	278	117	38	13.71
107	01/10/2011 – 31/12/2011	92	14975	315	259	25	7.80
108	01/01/2012 – 31/03/2012	91	15066	335	216	22	6.41
109	01/04/2012 – 30/06/2012	91	15157	322	95	44	13.63
110	01/07/2012 – 30/09/2012	92	15249	202	125	32	15.76
111	01/10/2012 – 31/12/2012	92	15341	191	266	9	4.96

2.6.2.4.7 Model evapotranspiration

In MODFLOW the evapotranspiration (ET) package simulates ET from shallow water tables based on a root extinction depth (m) and a maximum groundwater extraction rate (mm/yr). The extinction depth identifies the water table depth below natural surface below which no ET will occur; see for example Shah et al. (2007). In the current application, the extinction depth was based on the vegetation root depth assigned in the various farming system models used to estimate recharge within the CAT modelling framework as reported in Beverly et al. (2011). The extinction depths vary from 800 mm for annual pasture to 7 m for forests. The maximum evapotranspiration rate was calculated as the difference between potential daily ET and estimated daily vegetative ET as predicted using the CAT modelling framework. This approach ensures that the sum of estimated daily vegetative ET from the unsaturated zone and the assigned maximum groundwater ET from the saturated zone cannot exceed daily potential ET calculated from meteorological data

2.6.2.4.8 Model rivers and drains

A total of 197 river gauges were identified within the model area representing all of the major rivers. Daily gauge level data was sourced from the Victorian Department of Environment, Land, Water and Planning Water Measurement Information System (WMIS, 2015). A list of the river gauges is provided in Table 12 to Table 18 for key river basins.

Only main stems of the major rivers were included in the model. These river reaches were identified using the DEPI hydro25 spatial data set (DEPI, 2014). The river classification was used to vary river incision depth (depth below the ground surface as defined by the digital elevation model) and width attributes. In the absence of recorded stage height information, river classification was used to estimate river stage heights. A total of 22,573 river cells are included in the model. Fifty-one gauges were selected to calibrate the catchment modelling framework in unregulated catchments based on Base Flow Indexes and observed stream flows.

Drainage channels and man-made drainage features in the Macalister Irrigation District (MID) were included in the model based on available drainage network mapping (Figure 121). This information was sourced from Southern Rural Water (SRW) and the DEPI Corporate Spatial Data library. Drainage cells are assigned to the uppermost cells within the model to capture groundwater discharge processes. Drain cells in MODFLOW can only act as groundwater discharge points and as such those cells outside drainage channels will be characterised as having a bed elevation equivalent to ground surface elevation. A total of 410,504 drainage cells are incorporated in the model. Apart from 3 river gauges sourced from the WMIS, SRW also has 15 gauges (Figure 121 and Table 19) monitored drainage from the MID. The measurements commenced between 1997 and 2005. Of the 15 gauges, six were selected to calibrate the catchment modelling framework based on observed discharge. The mean monthly discharge and annual discharge at these six gauges are presented in Figure 122 and Figure 123, respectively.

Table 12 River gauges for East Gippsland

Site ID	Site name	Easting	Northing	Gauge zero (Ahd)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
221001	GENOA RIVER @ ROCKTON	705825	5887218	414.72	26/05/1993		125.6		0.28
221201	CANN RIVER (WEST BRANCH) @ WEERAGUA	694682	5861473	153.96	21/02/1957		311		0.51
221202	GENOA RIVER @ WANGARABELL	721597.1	5858290.5	0	13/10/1927	30/06/1929	780		0.42
221203	BETKA RIVER @ MALLACOOTA	737895.1	5836091.4	0	26/01/1966	24/07/1972	117		0.37
221204	THURRA RIVER @ POINT HICKS	699200	5822200	0	17/05/1966	28/07/1978	345		0.43
221205	BEMM RIVER @ BEMM RIVER	671893.8	5821410.8	0	28/06/1966	5/06/1975	935		0.55
221206	CANN RIVER @ NOORINBEE	694397	5854712.4	0	31/05/1967	3/02/1971	541		0.43
221207	ERRINUNDRA RIVER @ ERRINUNDRA	669418	5853798	0	28/07/1971		162		0.65
221208	WINGAN RIVER @ WINGAN INLET NATIONAL PARK	719710.3	5825779.5	0	14/12/1982		420		0.39
221209	CANN RIVER (EAST BRANCH) @ WEERAGUA	695470	5863398	0	23/10/1972		154		0.36
221210	GENOA RIVER @ THE GORGE	723046	5856007	0	22/08/1972		837		0.34
221211	COMBIENBAR RIVER @ COMBIENBAR	675439	5854433	0	12/08/1974		179		0.48
221212	BEMM RIVER @ PRINCES HIGHWAY	667855	5836059	0	30/04/1975		725		0.59
221213	GOOLENGOOK RIVER @ D/S OF ARTE RIVER JUNCTION	663700	5846900	0	1/05/1978	18/12/1986	171		0.69
221214	CANN RIVER @ D/S OF CANN RIVER	688655	5836283	0	26/07/1979		675		0.44
221216	GENOA RIVER @ D/S OF BIG FLAT CREEK JUNCTION	722308.7	5858209.9	0	23/05/1967	10/12/1970	829		0.43
221217	GENOA RIVER @ GIPSY POINT (WOOD'S JETTY)	736900	5848600	-1.3	8/07/1992	3/11/1998	0		
221218	BETKA RIVER @ MINERS TRACK	732688	5835801	0	16/01/1996		0		0.29

221222	HENSLEIGH CREEK U/S COMBIENBAR	679158	5863650	0	18/05/2006	17/11/2010	0		
221223	COMBIENBAR RIVER @ TIGER SNAKE CK	680158	5864336	0	18/05/2006	17/11/2010	0		
221224	CANN RIVER U/S CANN RIVER OFFTAKE	690544	5843171	0	11/03/2009		0		0.52
221225	BEMM RIVER U/S OF PUMPHOUSE	671929	5822377	0			0		0.44
221800	RAINGAUGE (GENOA RIVER) @ THE GORGE	722715	5855916.4	0	22/08/1972		0		

Table 13 River gauges for Latrobe Basin

Site ID	Site name	Easting	Northing	Gauge zero (mAHD)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
226005	LATROBE RIVER @ THOMS BRIDGE	448418	5775480	0	24/05/1960		2657		0.57
226006	TYERS RIVER @ BOOLA	448568.9	5781803	112.027	16/04/1958		293		0.44
226007	TYERS RIVER @ BROWNS	443476	5788600	169.359	17/08/1961		207		0.60
226008	TYERS RIVER WEST BRANCH @ MORGANS MILL	439256	5800120	0	27/04/1960		80		0.64
226012	TANJIL RIVER EAST BRANCH @ TANJIL BREN	429307.7	5812543.1	0	18/01/1961	11/08/1971	12		0.65
226016	WATERHOLE CREEK @ MORWELL	449045.2	5767997.4	60.56	22/08/1961	15/02/1982	41		0.42
226017	JACOBS CREEK @ O'TOOLES	446350	5788246	0	16/04/1962		36		0.43
226021	NARRACAN CREEK @ MOE	435969	5775832	0	26/06/1996		0		0.69
226023	TRARALGON CREEK @ TRARALGON	460064	5772541	32.673	18/09/1998		189		0.48
226027	LATROBE RIVER AT SWING BRIDGE	511200	5778084	0	7/05/2010		0		0.41
226028	TYERS R @ PUMP HOUSE	451503	5778560	0	5/04/2007		0		0.63
226033	LATROBE RIVER @ SCARNES BRIDGE	460763	5777041	21.185	20/12/1996		0		0.44
226039	BILLY CREEK @ U/S OF OFFTAKE WEIR	446116.2	5755155.9	0	2/03/1967	8/05/1968	22		0.57
226041	LAKE WELLINGTON @ BULL BAY	532876	5780415	0	25/02/1991		0		
226202	TYERS RIVER @ GOULD	444451.2	5785659.5	0	19/05/1926	28/02/1941	220		0.59
226204	LATROBE RIVER @ WILLOW GROVE	426308	5784017	0	17/10/1966		580		0.74
226205	LATROBE RIVER @ NOOJEE	414035	5804037	0	1/05/1996		290		0.79
226206	LATROBE RIVER @ APM MARYVALE	452119.2	5774427.3	27.546	2/01/1946	3/05/1977	3002		0.62
226209	MOE RIVER @ DARNUM	412633	5770880	79.598	19/10/1960		214		0.48
226216	TANJIL RIVER @ TANJIL SOUTH	433560	5783395	69.245	5/04/1955		358		0.70
226217	LATROBE RIVER @ HAWTHORN BRIDGE	419490.7	5796547.9	0	2/06/1955	9/01/1989	440		0.73
226218	NARRACAN CREEK @ THORPDALE	428843	5763687	0	22/06/1955		66		0.75

Site ID	Site name	Easting	Northing	Gauge zero (mAHD)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
226219	TOORONGA RIVER @ NOOJEE	415838.9	5810012	0	1/10/1924	1/07/1933	65		0.78
226220	LOCH RIVER @ NOOJEE	412644	5808497	0	25/04/1978		106		0.74
226222	LATROBE RIVER @ NEAR NOOJEE (US ADA R JUNCT.)	402650	5806658	272.304	10/05/1971		62		0.80
226223	LATROBE RIVER @ NEERIM EAST	414328.5	5800194.3	0	16/03/1972	8/01/1979	378		0.77
226224	LATROBE RIVER @ ROSEDALE (ANABRANCH)	481555	5777709	9.7	1/12/1936		4144		0.12
226226	TANJIL RIVER @ TANJIL JUNCTION	429155	5796100	0	25/05/1960		289		0.69
226227	LATROBE RIVER @ KILMANY SOUTH	492900	5778721	2.571	16/12/1976		4464		0.62
226228	LATROBE RIVER @ ROSEDALE (MAIN STREAM)	481748	5778351	9.7	1/12/1936		4144		0.62
226229	TANJIL RIVER @ D/S OF BLUE ROCK DAM	432764.2	5784646.8	75.315	11/05/1979	28/02/1982	352		0.71
226232	TANJIL RIVER @ MOE-WALHALLA ROAD BRIDGE	0	0	0	17/05/1990	5/06/1990	514		
226233	TANJIL RIVER @ U/S OF SERPENTINE CREEK	435276.4	5783132.8	0	16/07/1992	12/12/2006	0		0.74
226235	TYERS RIVER @ TYERS JUNCTION	441506	5798197	0	20/08/2003		132.2		0.61
226244	TYERS R EAST BRANCH @ CORRINGAL SCOUT CAMP	441496	5798505	0	27/10/2004	18/09/2008	0		
226245	TYERS R WEST BRANCH U/S SOUTH FACE RD	436327	5807354	0	1/11/2004	24/02/2009	0		
226246	TYERS R WEST BRANCH D/S SOUTH FACE RD	436123	5807237	0	28/10/2004	24/02/2009	0		
226247	HOPE CK U/S SOUTHFACE ROAD BRIDGE	434283	5810028	0	26/03/2007	24/02/2009	0		
226248	HOPE CK D/S SOUTHFACE ROAD BRIDGE	434267	5809990	0	26/03/2007	24/02/2009	0		
226400	LATROBE RIVER @ YALLOURN	437171.9	5776866.3	0	1/11/1923		1940		
226402	MOE DRAIN @ TRAFALGAR EAST	431070	5774351	0	7/06/1957		622		
226407	MORWELL RIVER @ BOOLARRA	439351	5748787	98.302	9/05/1972		114		
226408	MORWELL R @ YALLOURN	444702	5770110.4	0	21/04/2004		622		

Site ID	Site name	Easting	Northing	Gauge zero (mAHD)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
226410	TRARALGON CREEK @ KOORNALLA	459050	5758231	0	9/07/1953		89		
226415	TRARALGON CREEK @ TRARALGON SOUTH (JONES RD)	459805	5764127	60	27/05/1976		128		
226602	AREA 2 SITE1 @ DOWDS MORASS NTH	515887	5777885	-0.016	17/06/2003	24/09/2009	0		
226603	AREA 4 SITE 2 @ DOWDS MORASS STH	516572	5776987	-0.016	17/06/2003		0		
226605	LAKE VICTORIA AT MCLENNAN'S STRAIT	539492.4	5787708	0	17/11/2010		0		
226606	LAKE VICTORIA AT LOCH SPORT	551177	5789006		26/11/2010				
226607	MCMILLAN STRAIT AT PAYNESVILLE	564019	5803744.2		21/10/2010				
226608	LAKE KING AT METUNG	576509	5807127.8		17/11/2010				
226609	CUNNINGHAM ARM AT BULLOCK ISLAND	585591	5806582.2		19/10/2010				
226700	LOY YANG OUTFALL TO TRARALGON CREEK	0	0	0	17/12/1997	7/02/2000	0		
226702	MORWELL GROSS POLLUTION TRAP D/S CIRCULAR PIPE	447900	5766700	0	1/06/1998	7/10/1998	0		
226801	RAINGAUGE (REPRESENTATIVE BASIN) @ LATROBE NO. 2	399410	5810382.1	0	19/01/1982	17/08/1988	0		
226802	RAINGAUGE (REPRESENTATIVE BASIN) @ LATROBE NO. 3	398477.4	5802787.5	0	19/01/1982	6/03/1986	0		
226804	RAINGAUGE (SITE 3) @ WALHALLA ST - NEWBOROUGH	438000	5772500	0	6/12/1994	16/10/1995	0		
226805	RAINGAUGE (SITE 4) @ MOE INDOOR RECREATION CENTRE	437018.3	5772948.1	0	7/12/1994	16/10/1995	0		
226814	RAIN GAUGE @ MT TASSIE	461784	5750077	0	3/12/1998		0		
226815	RAIN GAUGE (TRARALGON CK) @ TRARALGON - EPA YARD	458982	5772514	0	25/05/1999		0		
226816	RAIN GAUGE @ MT HOOGHLY	453401	5750509	0	29/09/1999	15/05/2008	0		
226817	RAIN GAUGE @ LE ROY QUARRY	457656	5750650	0	30/09/1999	31/10/2009	0		
226818	RAIN GAUGE @ BALOOK	459952	5746341	0	10/06/1999		0		

Site ID	Site name	Easting	Northing	Gauge zero (mAHD)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
226819	RAIN GAUGE @ CALIGNEE NORTH	462063	5758780	0	25/05/1999		0		
226825	RAINGAUGE @ MOE SOUTH	434231.7	5769648.9		6/10/2009				
226826	RAINGAUGE AT YARRAGON SOUTH	420511	5763367.1		21/10/2009				
226827	RAINGAUGE @ THORPDALE PEAK	431275	5760002.4		17/09/2009				
226828	RAINGAUGE @ JEERALANG SOUTH HALLAMS RD	451008.4	5752916		6/10/2009	16/11/2011			
226829	RAINGAUGE AT JERRALANG, DOBBINS ROAD	450883.6	5754699.5		29/01/2013				

Table 14 River gauges for Mitchell Basin

Site ID	Site name	Easting	Northing	Gauge zero (Ahd)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
224200	MITCHELL RIVER @ BAIRNSDALE	552241	5813267	0			4425		
224201	WONNANGATTA RIVER @ WATERFORD	514714	5850745	175.337	15/07/1976		1979		
224203	MITCHELL RIVER @ GLENALADALE	533010	5820334	28.951	22/02/1991		3903		
224205	DARGO RIVER @ DARGO (UPPER SITE)	524129.9	5861627.7	0	1/06/1953	26/06/1974	539		
224206	WONNANGATTA RIVER @ CROOKED RIVER	507891	5859903	240.829	13/04/1977		1096		
224207	WONGUNGARRA RIVER @ GUYS	508800	5862200	247.234	7/05/1953	10/01/1989	736		
224208	MITCHELL RIVER @ HOWITT DAM SITE	532433.8	5827894.3	51.586	14/02/1969	22/12/1975	3761		
224209	COBBANNAH CREEK @ NEAR BAIRNSDALE	530900	5831600	0	15/05/1970	1/07/1987	106		
224210	WONNANGATTA RIVER @ KINGSWELL BRIDGE (HAWKHURST)	510185.8	5859581.7	224.768	12/02/1970	25/03/1981	1883		
224213	DARGO RIVER @ LOWER DARGO ROAD	523752	5850152	172.824	24/05/1973		676		
224214	WENTWORTH RIVER @ TABBERABBERA	534808	5850099	0	4/07/1974		443		
224215	MITCHELL RIVER @ ANGUSVALE (TABBERABBERA)	529928	5838289	92.644	28/05/1975	30/09/2008	3430		
224216	CLIFTON CREEK @ WY YUNG	554294.5	5816639.7	0	28/01/1977	4/01/1979	129		
224217	MITCHELL RIVER @ ROSEHILL	550366	5814542	0	2/04/2003		4413		
224220	RAIN GAUGE (BOGGY CREEK) @ BULLUMWAAL	548565.5	5830013.3	178.885	26/02/1991		83		
224222	MITCHELL RIVER U/S GLENALADALE PUMPHOUSE	532443	5823351	0	18/12/2009		0		

Table 15 River gauges for Snowy Basin

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
222200	SNOWY RIVER @ JARRAHMOND	620071	5830901	0	30/06/1971		13421		
222201	SNOWY RIVER @ ORBOST	627898	5825644.4	-0.141	27/03/1997		13572		
222202	BRODRIBB RIVER @ SARDINE CREEK	636752	5847240	78.591	16/06/1998		658		
222203	SNOWY RIVER @ MARLO JETTY	634504.8	5815384.5	-0.745	25/06/1934	18/01/1998	0		
222204	SNOWY RIVER @ BETE BELONG	623487.8	5824589.9	0	21/10/1938	26/07/1949	13540		
222205	SNOWY RIVER @ NEWMERELLA-LOCHEND ROAD	632611.9	5821910.2	-0.479	1/03/1960	27/01/1983	13600		
222206	BUCHAN RIVER @ BUCHAN	603711	5849459	74.85	27/03/1926		822		
222207	BUCHAN RIVER @ MURRINDAL	609403	5848400.8	0	15/02/1951	21/11/1972	1204		
222209	SNOWY RIVER @ MCKILLOP BRIDGE	625612	5894902	0	5/04/1967		10619		
222210	DEDDICK RIVER @ DEDDICK (CASEYS)	626577.7	5894693.7	0	5/04/1973		857		
222212	SNOWY RIVER @ BASIN CREEK NEAR BUCHAN	613458.7	5850738.1	0	4/05/1932	10/01/1934	11836		
222213	SUGGAN BUGGAN RIVER @ SUGGAN BUGGAN	618048	5909278	0	25/06/1974		361		
222214	ROCKY RIVER @ NEAR ORBOST	645109.5	5833372.7	0	8/12/1969	17/03/1978	20		
222216	MURRINDAL RIVER @ BASIN ROAD (BUCHAN)	608500	5849900	0	4/02/1976	30/06/1987	302		
222217	RODGER RIVER @ JACKSONS CROSSING	620346	5858744	0	3/06/1976		447		
222218	LITTLE RIVER @ WULGULMERANG	616400	5897200	0	21/04/1977	18/07/1984	88		
222219	SNOWY RIVER @ D/S OF BASIN CREEK	612580	5848984	0	12/12/1978		11964		
222221	BUCHAN RIVER @ EGW OFFTAKE	603874	5852271	0	14/05/2009		0		
222222	ROCKY RIVER U/S OT THE WEIR	645938	5834053	0	11/03/2009		0		
222400	MOYANGUL RIVER @ LOOKOUT NEAR TIN MINE	613203.5	5941897.7	0	14/03/1955	14/11/1963	29		
222401	INGEEGOODBEE RIVER @ D/S OF TIN MINE HUTS	613098.4	5933947.3	0	19/05/1955	14/11/1963	21		

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
222403	BUCHAN RIVER @ GLENMORE	600499.4	5879843.5	0	27/01/1955	22/07/1969	513		
222404	MELLICK MUNJIE CREEK @ GILLINGALL	598595.5	5877355.2	0	5/07/1955	22/07/1969	70		

Table 16 River gauges for South Gippsland region

Site ID	Site name	Easting	Northing	Gauge zero (Ahd)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
227001	MERRIMAN CREEK @ SEASPRAY	514294.7	5754491	0	29/09/1966	17/06/1971	525		
227200	TARRA RIVER @ YARRAM	471649	5734286	0	18/02/1976		215		
227201	BRUTHEN CREEK @ WOODSIDE	488800	5735750	0	1/03/1946	30/09/1960	174		
227202	TARWIN RIVER @ MEENIYAN	412165	5729150	0	22/06/1955		1067		
227203	FRANKLIN RIVER @ HENWOODS BRIDGE	436475.8	5725293.9	0	3/12/1946	8/01/1985	12		
227205	MERRIMAN CREEK @ CALIGNEE SOUTH	469833	5755048	172.448	13/12/1965		36		
227210	BRUTHEN CREEK @ CARRAJUNG LOWER	477651	5750309	0	7/08/1952		18		
227211	AGNES RIVER @ TOORA	445387	5722973	0	10/01/1957		67		
227213	JACK RIVER @ JACK RIVER	459739	5735728	0	1/12/1962		34		
227216	ALBERT RIVER @ HIAWATHA (BELOW FALLS)	453863.5	5735533.5	0	25/06/1964	23/02/1989	41		
227217	LILLYPILLY CREEK @ STAIRCASE	442292	5680222.7	0	2/09/1965	15/01/1974	5		
227219	BASS RIVER @ LOCH	388609	5753722	0	1/04/1966		52		
227220	GREIG CREEK @ MUMFORDS	473100	5743600	0	6/05/1968	2/12/1998	25		
227221	BODMAN CREEK @ BRIDGES	476725.7	5746055.5	0	7/05/1968	20/10/1978	15		
227222	SPRING CREEK @ BOWDENS	475282.4	5742352.5	65.909	20/05/1968	13/06/1975	10		
227223	MACKS CREEK @ RICHARDS	467870.1	5741586.5	0	24/04/1968	15/06/1987	19		
227224	WOMERAH CREEK @ TARR VALLEY ROAD	462201	5741376.9	0	29/04/1968	20/12/1982	1		
227225	TARRA RIVER @ FISCHERS	461190	5741983	0	24/04/1968		16		
227226	TARWIN RIVER EAST BRANCH @ DUMBALK NORTH	426838	5738399	0	8/01/1969		127		
227227	WILKUR CREEK @ LEONGATHA	408948	5750056	0	31/07/1970		106		
227228	TARWIN RIVER EAST BRANCH @ MIRBOO	433155.3	5737488.6	0	30/04/1971	18/06/1987	43		

Site ID	Site name	Easting	Northing	Gauge zero (Ahd)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
227231	BASS RIVER @ GLEN FORBES SOUTH	370463	5741320	0	30/03/1973		233		
227232	LANCE CREEK U/S LANCE CREEK RESERVOIR	383783	5738738	0	31/03/2008		14		
227234	SPRING CREEK @ BEAUMONT	475276.8	5744201.8	0	3/04/1975	15/12/1982	7		
227235	MIDDLE CREEK @ TALL TIMBERS	460742.6	5742294.6	0	27/04/1978	18/01/1989	9		
227236	POWLETT RIVER @ D/S FOSTER CREEK JUNCTION	387508	5731353	0	18/05/1979		228		
227237	FRANKLIN RIVER @ TOORA	439771	5724088	0	7/04/1983		75		
227238	FOSTER CREEK @ DAM SITE	387050.1	5739746.7	0	8/06/1979	17/01/1989	55		
227239	MERRIMAN CREEK @ STRADBROKE WEST	492658	5764652	71.868	18/11/1983		256		
227240	MERRIMAN CREEK @ PROSPECT ROAD SEASPRAY	514320	5754179	2.544	26/08/1983		529		
227242	MERRIMAN CREEK @ SEASPRAY TOWNSHIP	516203	5752529	0	6/03/1990		8		
227243	BRUTHEN CREEK @ D/S REEDY CREEK	484778	5747810	79.91	13/05/1992		124		
227244	DEEP CREEK @ FOSTER	432312	5725707	0	29/04/1993		0		
227245	LITTLE BASS RIVER @ POOWONG U/S LITTLE BASS RES.	39050	5753576	0	18/05/1999		0		
227246	COALITION CREEK	396827	5748087.4	0	8/06/2004		0		
227248	BELLVIEW CREEK U/S BELLVIEW RESERVOIR	396367	5749105	0	18/05/1999		0		
227249	RUBY CREEK @ ARAWATA	402379	5748848	0	23/07/2008		0		
227251	TARRA RIVER @ TARRA WEIR OFFTAKE	463301	5741305	0	27/10/2004		0		
227264	COALITION CREEK @ LEONGATHA (SPENCERS ROAD BRIDGE)	409001	5743754	0	21/10/2008		0		
227265	GOLDEN CREEK @ BLACK SWAMP ROAD	428266	5711026	0	15/02/2008	18/11/2008	0		
227266	TARWIN RIVER @ KOONWARRA	408996	5735402	0	22/09/2008		0		

Site ID	Site name	Easting	Northing	Gauge zero (Ahd)	Site start date	Site cease date	Drainage area (km^2)	BFI GHD	BFI
227270	FOSTER CREEK AT KORUMBURRA	394617.6	5745540		13/10/2011				

Table 17 River gauges for Tambo Basin

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
223202	TAMBO RIVER @ SWIFTS CREEK	564619	5875047	280.863	8/03/1977		943		
223204	NICHOLSON RIVER @ DEPTFORD	561543	5839104	0	12/05/1961		287		
223205	TAMBO RIVER @ D/S OF RAMROD CREEK	576710	5830147	15.452	9/06/1965		2681		
223206	TAMBO RIVER @ BINDI	571424.2	5896694.3	0	8/08/1957	19/12/1974	401		
223207	TIMBARRA RIVER @ TIMBARRA	592900	5869900	0	9/09/1957	4/06/1973	205		
223208	TAMBO RIVER @ BINDI (NEAR JUNCTION CREEK)	568710	5887104	0	21/03/1974	14/07/2003	523		
223209	TAMBO RIVER @ BATTENS LANDING	574796.1	5820757.9	0	26/01/1977		2781		
223210	NICHOLSON RIVER @ SARSFIELD	562646	5823050	0	21/09/1977		471		
223212	TIMBARRA RIVER @ D/S OF WILKINSON CREEK	594066	5855069	0	6/05/1982		438		
223213	TAMBO RIVER @ D/S OF DUGGAN CREEK	578509	5904321	746.726	16/09/1987		96		
223214	TAMBO RIVER @ U/S OF SMITH CREEK	582588	5909736	0	2/03/1989		32		
223215	HAUNTED STREAM @ HELLS GATE	573015	5851389	153.892	8/02/1990		180		
223216	TAMBO RIVER U/S SWIFTS CK OFFTAKE	563729	5877748	0	20/05/2009		0		
223217	NICHOLSON RIVER AT PUMP HOUSE	564088	5821594	0	20/01/2011		0		
223402	TIMBARRA RIVER @ NUNNIONG PLAINS	587028.3	5888208.6	0	22/06/1955	16/02/1960	16		
223403	TAMBO RIVER @ NUNNIONG PLAINS	583943.9	5892462.9	0	21/06/1955	16/02/1960	39		
223800	RAINGAUGE (TAMBO RIVER) @ MOUNT ELIZABETH	582300	5850700	0	15/01/1985	20/10/2004	0		
223801	RAIN GAUGE (TAMBO RIVER) @ MT ELIZABETH HELIPAD	581909	5850809	0	20/10/2004	19/01/2011	0		
223802	RAINGAUGE AT MOUNT ELIZABETH SOMMERVILLE TRACK	580733	5851999		19/01/2011				

Table 18 River gauges for Thomson Basin

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
225019	NORTH CASCADE CREEK @ THOMSON VALLEY ROAD	441836.2	5815577.5	0	11/01/1962	6/06/1974	11		
225105	THOMSON RIVER @ NEWLAND ROAD	427654.1	5819829.7	0	30/03/1954	1/05/1984	16		
225114	THOMSON RIVER @ D/S WHITELAWS CREEK	436711	5825795	0	27/03/1987		155.3		
225200	THOMSON RIVER @ HEYFIELD	480693	5795763	35.846	17/01/1991		1238		
225201	AVON RIVER @ STRATFORD	506676	5797653	0	1/11/1976		1485		
225204	MACALISTER RIVER @ LAKE GLENMAGGIE (TAIL GAUGE)	482885	5805021	47.015	28/09/1966		1891		
225207	THOMSON RIVER @ WALHALLA	449064.3	5798590.9	0	9/03/1950	22/05/1952	875		
225209	MACALISTER RIVER @ LICOLA	466762	5835198	2	1/08/1952		1233		
225210	THOMSON RIVER @ THE NARROWS	447551	5805990	247.08	9/04/1957		518		
225212	THOMSON RIVER @ WANDOCKA	489554	5792978	19.423	1/03/1977		1417		
225213	ABERFELDY RIVER @ BEARDMORE	450135	5810238	305.552	27/06/1963		311		
225216	JORDAN RIVER @ ABERFELDY	439747.8	5829099.3	0	4/10/1971	18/07/1972	124		
225217	BARKLY RIVER @ GLENCAIRN	461700	5842800	263.1	12/05/1966	4/01/1989	248		
225218	FREESTONE CREEK @ BRIAGALONG	508366.4	5815232.8	63.238	14/07/1975		309		
225219	MACALISTER RIVER @ GLENCAIRN	461689	5847757	293.54	7/04/1967		570		
225221	MACALISTER RIVER @ STRINGYBARK CREEK	470738	5819709	105.249	18/03/1968		1542		
225222	GLENMAGGIE CREEK @ SEATON (AUBREYS)	471117.4	5803309.8	111.285	10/03/1970	18/12/1975	141		
225223	VALENCIA CREEK @ GILLIO ROAD	499321	5822633	85.481	26/03/1991		195		
225224	AVON RIVER @ THE CHANNEL	489868	5816150	72	12/07/1972		554		

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
225225	MACALISTER RIVER @ LAKE GLENMAGGIE (HEAD GAUGE)	482418.6	5804322.1		26/01/1925				
225228	THOMSON RIVER @ COWWARR TIMBER WEIR H.G.	469855.4	5794299.7	-0.96	1/01/1958		1093		
225230	GLENMAGGIE CREEK @ THE GORGE	469772	5803687	120.847	2/05/1975		139		
225231	THOMSON RIVER @ U/S OF COWWARR WEIR	467065	5796878	69.4	1/04/1976		1080		
225232	THOMSON RIVER @ BUNDALAGUAH	499308	5789148	5.094	3/11/1976		3538		
225233	PERRY RIVER @ PERRY BRIDGE	523288.7	5793397.5	-0.938	24/12/1976	19/11/1982	357		
225234	AVON RIVER @ CLYDEBANK (CHINN'S BRIDGE)	515238	5791515	0	29/06/2004		1584		
225236	RAINBOW CREEK @ HEYFIELD	480686	5793911	33.837	30/04/1992		0		
225247	MACALISTER RIVER @ RIVERSLEA	498044.5	5791335.7	0	11/01/2001		0		
225248	BOGGY CREEK @ CORNWALLS ROAD	492831	5793649.7	0	29/08/2008		0		
225255	AVON RIVER U/S VALENCIA CK JUNCTION	498324	5813965	0	30/06/2004		0		
225256	MACALISTER R D/S MAFFRA (SMITHS BR.)	498377	5793730	0	26/10/2005		0		
225600	LAKE WELLINGTON @ SALE	519212	5781295.6	0	1/12/1973	1/07/1977	0		
225703	THOMSON RIVER DIVERSION CHANNEL @ COWWARR WEIR	470010	5794250	0	5/02/2001	19/07/2007	0		
225711	LAKE WELLINGTON DRAIN @ 5 MILES 32 CHAIN MEASURING WEIR	512208.2	5787288.3	0	12/11/1976	3/05/2001	0		
225715	CENTRAL GIPPSLAND DRAIN 3 @ NAMBROK (RD 1066M)	488590	5786295	0	24/02/1980	15/04/2005	0		
225716	CENTRAL GIPPSLAND 1/2 DRAIN 3 @ DROP STRUCTURE (RD500)	491500	5784700	0	24/02/1980	4/02/2004	0		
225717	CENTRAL GIPPSLAND 2/3 DRAIN @ US OF DRAIN 3 (RD 500M)	491102	5783737	0	24/02/1980	15/04/2005	0		

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
225721	CENTRAL GIPPSLAND DRAIN NO 3/3 U/S OUTFALL	487050	5788350	0	29/05/2000	13/02/2004	0		
225722	CENTRAL GIPPSLAND DRAIN NO 3 D/S NO3 O/FALL	487100	5788300	0	29/05/2000	13/02/2004	0		
225723	CENTRAL GIPPSLAND DRAIN NO 1/3 @ D/S 11/4/1 JUNCTION	488200	5784600	0	29/05/2000	13/02/2004	0		
225724	CHANNEL O/FALL 11/4/1 U/S JUNCTION CG DR 1/3	488150	5784500	0	29/05/2000	15/04/2005	0		
225725	CENTRAL GIPPSLAND DRAIN NO 3 D/S O/FALL 11/1	490400	5783500	0	26/05/2000	15/04/2005	0		
225726	CENTRAL GIPPSLAND DRAIN NO 3 D/S RAILWAY LINE	491000	5781800	0	29/05/2000	15/04/2005	0		
225727	CENTRAL GIPPSLAND DRAIN NO 2/3 @ SOLDIERS RD	490100	5785600	0	26/05/2000	13/02/2004	0		
225737	CENTRAL GIPPSLAND DRAIN NO 8/2 @ DENISON ROAD	483978	5789779	0	28/05/2002	15/04/2005	0		
225738	CENTRAL GIPPSLAND DRAIN NO 2 @ SALE-TOONGABBIE ROAD	487500	5782800	0	28/05/2002	15/04/2005	0		
225739	CENTRAL GIPPSLAND DRAIN NO 2/2 @ DESSENTS	487311	5782836	0	28/05/2002	15/04/2005	0		
225740	CENTRAL GIPPSLAND DRAIN NO 2 U/S TINAMBA-ROSEDALE ROAD	487800	5781900	0	16/05/2002	15/04/2005	0		
225741	CENTRAL GIPPSLAND DRAIN NO 2 U/S NAMBROK ROAD	485335	5786592	0	16/05/2002	15/04/2005	0		
225742	CENTRAL GIPPSLAND DRAIN NO 2 U/S SALE-COWWARR ROAD	484488	5788744	0	28/05/2002	15/04/2005	0		
225743	CENTRAL GIPPSLAND DRAIN NO 6/2 U/S DENISON ROAD	483670	5788400	0	28/05/2002	15/04/2005	0		
225747	NOBLES O/FALL @ VALENCIA CK	498563	5813297	0	24/02/2004	1/07/2005	0		
225748	TINAMBA MAIN O/FALL @ MENBURN PARK	498214	5813767	0	25/02/2004	27/06/2005	0		

Site Id	Site Name	Easting	Northing	Gauge Zero (Ahd)	Site Start Date	Site Cease Date	Drainage Area (Sq.km)	BFI GHD	BFI
225801	RAIN GAUGE (MACALISTER RIVER) @ MURDERERS HILL	460964	5810725	0	8/06/1970		0		
225802	RAIN GAUGE (MACALISTER RIVER) @ MOUNT TAMBORITHA	472550	5853466	0	1/04/1986		0		
225809	RAIN GAUGE (AVON RIVER) @ MOUNT WELLINGTON	487412	5850069	0	21/05/1997		0		
225810	RAIN GAUGE (AVON RIVER) @ REEVE KNOB	500533.2	5846182	0	21/05/1997		0		
225819	RAINGAUGE @ MT USEFUL	456353	5827872	0	27/05/2002		0		
225823	RAINGAUGE AT BLANKET HILL	472533.6	5811892.1		26/07/2010				
225824	RAINGAUGE (MACALISTER RV) AT SNOWY RANGE	0	0		22/02/2011				
225825	RAINGAUGE (MACALISTER RV) AT HIGH RIDGE	0	0						
225826	RAINGAUGE (MACALISTER RV) AT MOUNT SUNDAY	448995	5867264		6/04/2011				

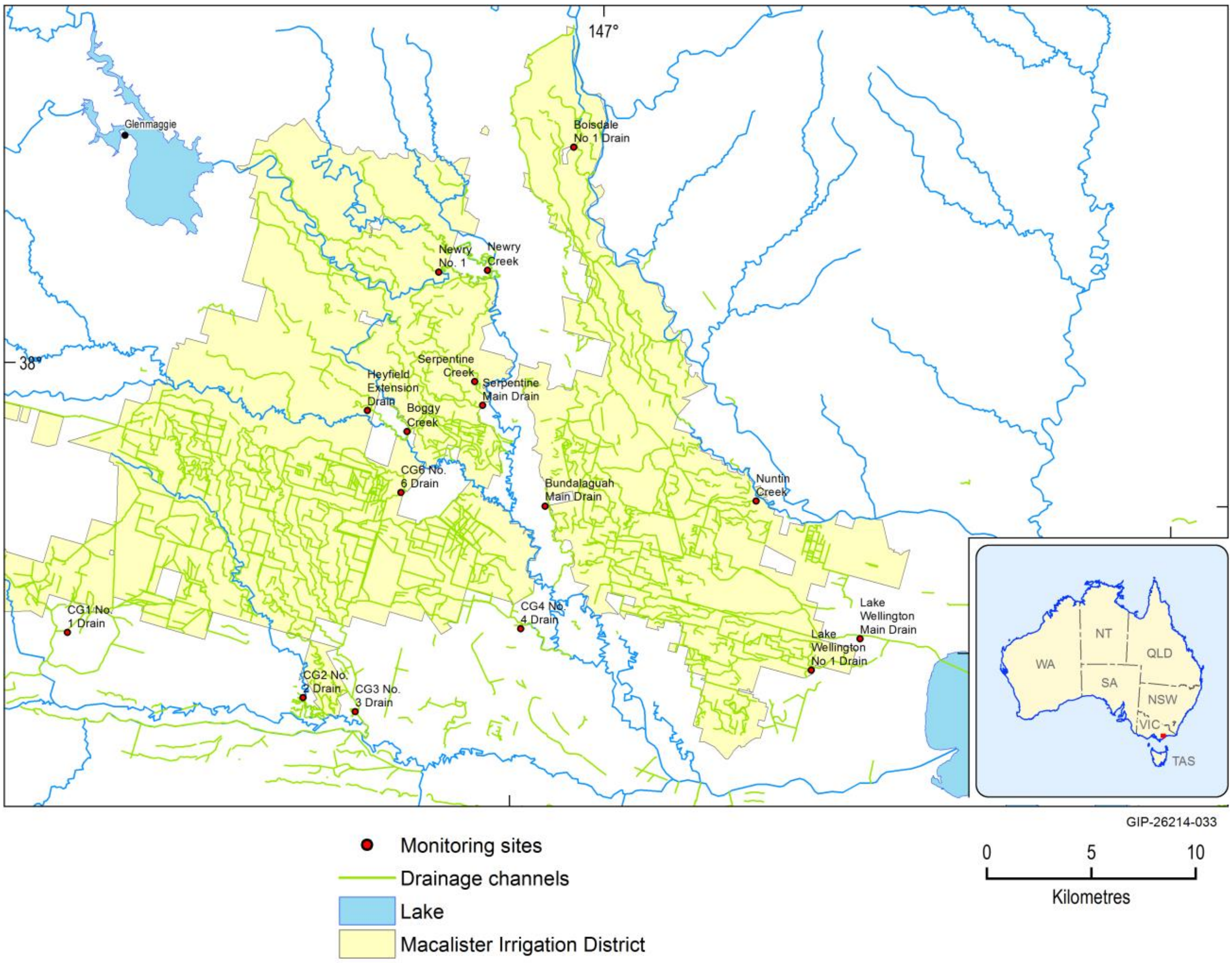


Figure 121 Drainage channels and monitoring sites in the Macalister Irrigation District

Table 19 Gauges monitoring drain from the Macalister Irrigation District (sourced from SWR)

Site code	Site name	Northings_z55	Eastings_z55	Data Record		Mean Annual Discharge (ML/yr)
				From	To	
225248A	Boggy Creek	5793110	493086	2001	2013	3710
225731A	Boisdale No 1 Drain	5807657	499378	2001	2013	623
225732A	Bundalaguah	5790315	500025	2001	2013	1696
225735A	CG1	5781567	478177	2001	2013	2106
225729A	CG2	5779780	489665	1999	2013	4960
225709A	CG3	5779400	492200	1997	2013	5431
225728A	CG4	5784308	499554	2000	2013	4161
225734A	CG6	5790162	493141	2001	2013	1955
225733A	Heyfield Ext	5793889	491102	2001	2013	2685
225730A	Lake Wellington Main Drain	5785744	515613	1997	2013	6133
225745A	Lake Wellington No 1 Drain	5783956	513485	2004	2013	1366
225245A	Newry Creek	5801277	495980	2000	2013	4251
225746A	Newry No 1	5800909	493696	2004	2013	388
225251A	Nuntin Creek	5791751	509946	2001	2013	1799

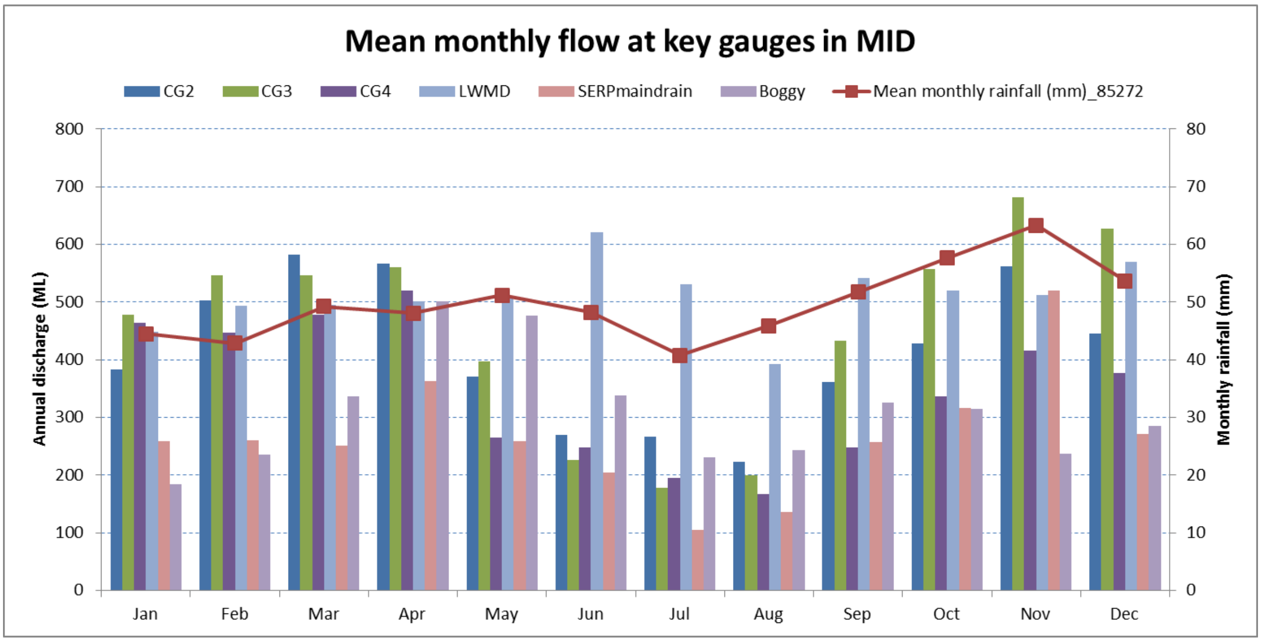


Figure 122 Mean monthly flow (ML/month) at key gauges monitored by SRW in the Macalister Irrigation District

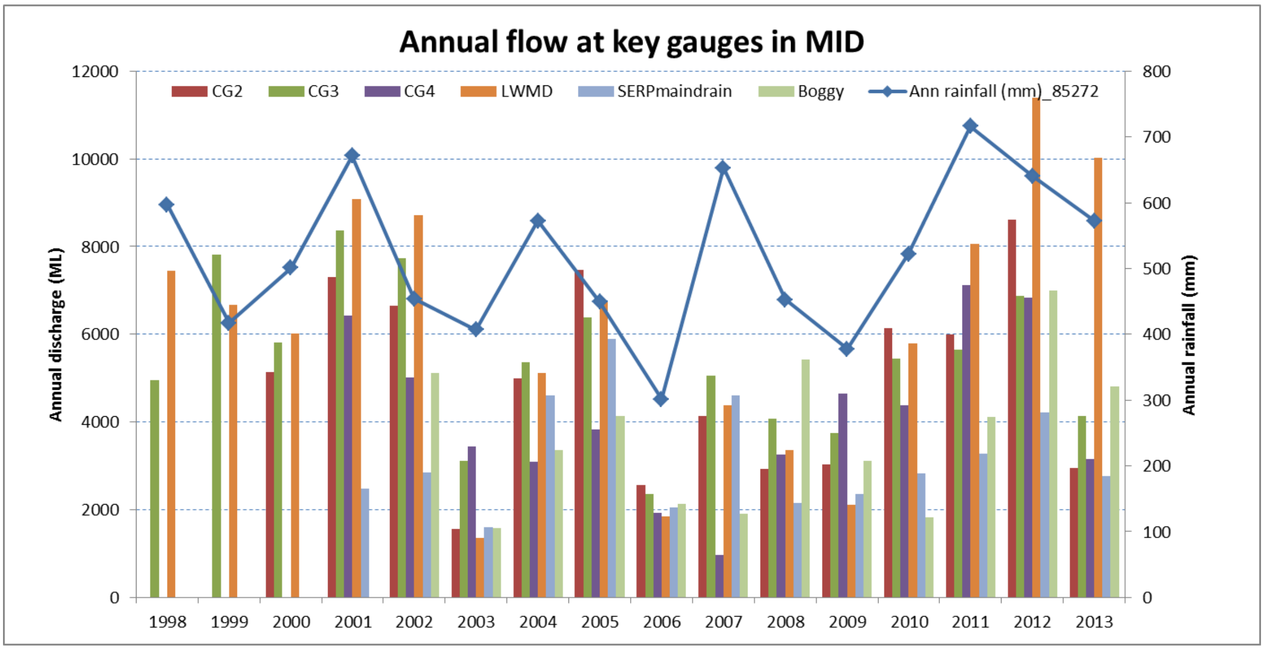


Figure 123 Annual Flow (ML/yr) at key gauges monitored by SRW in the Macalister Irrigation District

2.6.2.4.9 Surface water – groundwater interactions

Groundwater generally interacts with surface water through various processes and pathways. The development of groundwater often has impacts on major streams (and vice versa). As such it is necessary to manage groundwater and surface water resources in combination. This requires an understanding of the interconnectivity and processes underpinning surface water and groundwater interactions. In the context of water resource management it is important to understand and account for surface-groundwater water interaction when considering issues, including:

- double accounting of water resources
- impacts of groundwater pumping on stream flow, particularly flow depletion
- surface water requirements for downstream users
- water requirements for environmental purposes (e.g. floodplain, stream, wetland ecosystems)
- health of groundwater-dependent ecosystems (GDEs)
- conjunctive resource management strategy development and water allocation regime
- salinity impacts on water quality, salt loads, and ecosystem health
- management for climate variation/change and its impacts on groundwater–surface water systems.

To better inform the numerical groundwater model developed for the Gippsland region, a brief assessment of surface-groundwater water interaction across the study area was undertaken, based on available literature (e.g. DSE 2012; SKM 2012a, 2012b; Hofmann 2011) and analysis of groundwater and surface water information. DSE (2012) collated a state-wide dataset of groundwater and surface water interaction from numerous investigations across Victoria. The dataset described groundwater and surface water interaction in four broad classes: neutral/losing, gaining, variable and unclassified. SKM (2012a) undertook baseflow separation analysis for 180 stream gauges on unregulated rivers in Victoria. This included 51 gauges in the Gippsland region. The baseflow separation analysis was undertaken on historical river flow records up to 2012 and utilised a filter parameter of 0.98. The results of the analysis for the 51 stream gauges in the Gippsland region is summarised in Table 20.

The groundwater and surface water interaction in the main rivers in the Gippsland regions is summarised below.

In the **East Gippsland catchment** it is believed that the shallow aquifers are well connected to the rivers and all river reaches are generally gaining. The annual average base flow indices (BFI) are high, ranging from 0.72 to 0.79 (DSE, 2012; SKM, 2012b). As there are few groundwater monitoring bores in the catchment, these gaining conditions are not evidenced by a groundwater hydrograph.

In the **Latrobe catchment**, the river reaches in the upper part of the catchment (upstream of Traralgon) are generally gaining with high annual average BFI ranging from 0.71 to 0.79 (DSE, 2012; SKM, 2012b). The surface water – groundwater interaction in the lower part of the catchment is not well understood. Analysis of groundwater and stream flow data indicated that the flux exchange between the river and shallow aquifers is temporally and spatially variable. The river reaches near the Macalister Irrigation District (MID) might be dominated by gaining condition due to the elevated water table in the MID (Figure 125). Deep aquifers (e.g. Latrobe Group) are generally artesian and not in connection with rivers. Total licensed groundwater use in the catchment is estimated to be 14.4 GL/yr and extractions for mine dewatering are approximately twice this volume (SKM, 2012a). SKM (2012a) conclude that the impacts of current rates of groundwater extraction on the streamflow in the Latrobe River are low.

In the **Mitchell catchment,** the river reaches in the upper part of the catchment are generally gaining with annual average BFI ranging from 0.66 to 0.76 (DSE, 2012; SKM, 2012b). The surface-groundwater interaction in the lower part of the catchment was investigated by Monash University and SKM (2012a) using hydrogeochemistry and radon as a tracer (Hofmann, 2011) and using an analytical modelling approach respectively. There is a significant interaction between groundwater and surface water in the Mitchell River floodplain area. Hofmann (2011) found that these river reaches have gaining and losing sections and these invert depending on the flow conditions of the river. This is supported by groundwater hydrographs of the bores near the river (Figure 126). SKM (2012a) found that a high proportion of the Mitchell River catchment water yield is derived from the higher altitude areas in the upper catchment. Flows at Bairnsdale are much lower than those upstream and the Mitchell River becomes a losing stream as it emerges from the ranges (SKM, 2012a). SKM (2012a) estimated that the volume of discharge lost from the Mitchell River due to groundwater extraction is negligible when compared to the cumulative yearly discharge, but considerable during periods of low flow. During low flows periods, it is estimated that groundwater extraction can lead to a 13% reduction in streamflow. Groundwater levels are therefore considered to have a significant influence on the flow and aquatic habitat condition of the Mitchell River during low flow periods.

In the **Snowy catchment,** most river reaches are gaining with annual average BFI ranging from 0.69 to 0.79 (DSE, 2012; SKM, 2012a). The surface water – groundwater interaction in the lower part of the catchment is not well understood. Analysis of limited groundwater and stream flow data indicated that the flux exchange between the river and aquifers is variable (Figure 127).

In the **South Gippsland catchment**, based on stream flow analysis, most river reaches are gaining, with annual average BFI ranging from 0.64 to 0.78 (DSE, 2012; SKM, 2012a).

In the **Tambo catchment,** the river reaches in the upper part of the catchment are generally gaining, with annual average BFI ranging from 0.69 to 0.77 (DSE, 2012; SKM, 2012a). The surface water-groundwater interaction in the lower part of the catchment was investigated by Unland (2013) using hydrogeochemistry tracer techniques. Unland (2013) found that these river reaches have gaining and losing sections and these invert depending on the flow conditions of the river.

In the **Thomson catchment,** (including the Avon catchment) the river reaches in the upper part of the catchment are generally gaining, with annual average BFI ranging from 0.64 to 0.73 (DSE, 2012; SKM, 2012a). The river reaches in the MID are also dominated by gaining condition due to the elevated water table (Figure 128).

The surface water-groundwater interaction in the lower part of the catchment was investigated by Monash University using hydrogeochemistry and radon as a tracer (Hofmann, 2011). Hofmann (2011) found that these river reaches have gaining and losing sections and these invert depending on the flow conditions of the river.

There is significant groundwater/surface water interaction along the Avon River. SKM (2008) reported that the Avon River is strongly gaining along its main stem and along most tributaries. During periods of average rainfall, the groundwater baseflow component of stream flow is approximately 24–36% of average annual flow in the Avon River and 17–25% of average annual flow in Freestone Creek. Groundwater entitlement in the catchment is 13.8 GL/yr and current use is approximately 3.6 GL/yr. SKM (2008) suggests that current groundwater use reduces streamflow by approximately 3.4 GL/yr.

Based on these estimates it is suggested that if groundwater usage increases to full entitlement (assuming pumping infrastructure can support such usage) then groundwater extractions may have a significant impact on streamflow.

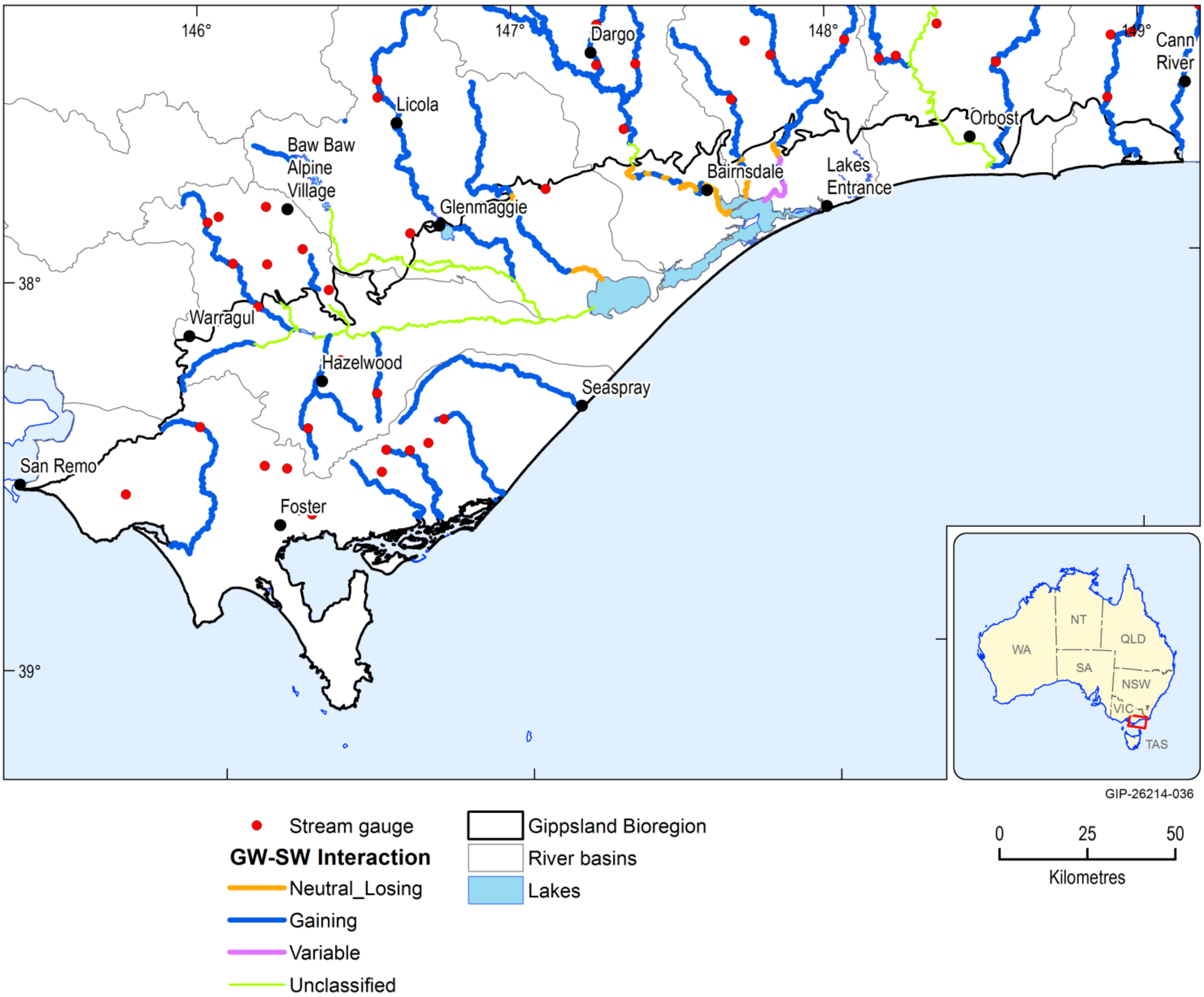


Figure 124 Surface-groundwater connectivity in the Gippsland region (source: data compiled by DSE in 2012)

Table 20 Estimated average baseflow index (BFI) (by season and annual) in 51 unregulated catchments in the Gippsland region (sourced from SKM 2012b)

Gauge ID	Gauge name	River basin	BFI Summer	BFI Autumn	BFI Winter	BFI Spring	BFI Annual
221201	Cann River (West Branch) @ Weeragua	East Gippsland	0.81	0.83	0.71	0.74	0.77
221204	Thurra River @ Point Hicks	East Gippsland	0.79	0.78	0.61	0.7	0.72
221207	Errinundra River @ Errinundra	East Gippsland	0.83	0.86	0.72	0.75	0.79
221208	Wingan River @ Wingan Inlet National Park	East Gippsland	0.82	0.79	0.6	0.71	0.73
221209	Cann River (East Branch) @ Weeragua	East Gippsland	0.81	0.8	0.67	0.72	0.75
221210	Genoa River @ The Gorge	East Gippsland	0.8	0.78	0.67	0.72	0.74
221211	Combienbar River @ Combienbar	East Gippsland	0.82	0.84	0.72	0.74	0.78
221212	Bemm River @ Princes Highway	East Gippsland	0.83	0.86	0.71	0.75	0.79
226008	Tyers River West Branch @ Morgans Mill	Latrobe River	0.83	0.83	0.7	0.71	0.77
226012	Tanjil River East Branch @ Tanjil Bren	Latrobe River	0.79	0.77	0.69	0.61	0.72
226016	Waterhole Creek @ Morwell	Latrobe River	0.9	0.82	0.68	0.73	0.78
226017	Jacobs Creek @ Otooles	Latrobe River	0.79	0.81	0.61	0.64	0.71
226204	Latrobe River @ Willow Grove	Latrobe River	0.86	0.87	0.72	0.73	0.8
226217	Latrobe River @ Hawthorn Bridge	Latrobe River	0.85	0.87	0.69	0.72	0.78
226219	Tooronga River @ Noojee	Latrobe River	0.85	0.88	0.7	0.72	0.79
226220	Loch River @ Noojee	Latrobe River	0.87	0.89	0.68	0.73	0.79
226226	Tanjil River @ Tanjil Junction	Latrobe River	0.83	0.87	0.67	0.65	0.75

Gauge ID	Gauge name	River basin	BFI Summer	BFI Autumn	BFI Winter	BFI Spring	BFI Annual
226407	Morwell River @ Boolarra	Latrobe River	0.85	0.82	0.58	0.66	0.72
226410	Traralgon Creek @ Koornalla	Latrobe River	0.84	0.81	0.55	0.64	0.71
224205	Dargo River @ Dargo (Upper Site)	Mitchell River	0.79	0.8	0.57	0.53	0.67
224209	Cobbannah Creek @ Near Bairnsdale	Mitchell River	0.67	0.69	0.66	0.68	0.67
224213	Dargo River @ Lower Dargo Road	Mitchell River	0.79	0.83	0.48	0.56	0.66
224214	Wentworth River @ Tabberabbera	Mitchell River	0.78	0.86	0.7	0.7	0.76
222202	Brodribb River @ Sardine Creek	Snowy River	0.83	0.86	0.71	0.75	0.79
222206	Buchan River @ Buchan	Snowy River	0.77	0.83	0.6	0.61	0.7
222210	Deddick River @ Deddick (Caseys)	Snowy River	0.79	0.83	0.76	0.77	0.74
222213	Suggan Buggan River @ Suggan Buggan	Snowy River	0.77	0.84	0.57	0.58	0.69
222216	Murrindal River @ Basin Road (Buchan)	Snowy River	0.76	0.75	0.62	0.65	0.7
222217	Rodger River @ Jacksons Crossing	Snowy River	0.79	0.85	0.67	0.71	0.75
227203	Franklin River @ Henwoods Bridge	South Gippsland	0.84	0.79	0.61	0.67	0.73
227210	Bruthen Creek @ Carrajung Lower	South Gippsland	0.82	0.83	0.63	0.68	0.74
227213	Jack River @ Jack River	South Gippsland	0.83	0.84	0.61	0.68	0.74
227220	Greig Creek @ Mumfords	South Gippsland	0.84	0.85	0.67	0.68	0.76
227223	Macks Creek @ Richards	South Gippsland	0.84	0.81	0.68	0.7	0.76
227225	Tarra River @ Fischers	South Gippsland	0.84	0.86	0.68	0.73	0.78
227226	Tarwin River East Branch @ Dumbalk North	South Gippsland	0.85	0.79	0.52	0.62	0.69

Gauge ID	Gauge name	River basin	BFI Summer	BFI Autumn	BFI Winter	BFI Spring	BFI Annual
227227	Wilkur Creek @ Leongatha	South Gippsland	0.84	0.74	0.45	0.6	0.64
227228	Tarwin River East Branch @ Mirboo	South Gippsland	0.85	0.76	0.54	0.62	0.69
227236	Powlett River @ D/S Foster Creek Junction	South Gippsland	0.9	0.8	0.42	0.6	0.67
227237	Franklin River @ Toora	South Gippsland	0.85	0.8	0.55	0.65	0.71
223204	Nicholson River @ Deptford	Tambo River	0.78	0.8	0.71	0.73	0.75
223206	Tambo River @ Bindi	Tambo River	0.78	0.84	0.57	0.58	0.69
223207	Timbarra River @ Timbarra	Tambo River	0.81	0.85	0.71	0.69	0.76
223211	Haunted Stream @ Stirling	Tambo River	0.78	0.83	0.72	0.67	0.75
223212	Timbarra River @ D/S Of Wilkinson Creek	Tambo River	0.79	0.86	0.69	0.69	0.76
223215	Haunted Stream @ Hells Gate	Tambo River	0.77	0.86	0.71	0.73	0.77
225019	North Cascade Creek @ Thomson Valley Road	Thomson River	0.8	0.77	0.7	0.62	0.64
225217	Barkly River @ Glencairn	Thomson River	0.81	0.83	0.45	0.57	0.66
225218	Freestone Creek @ Briagalong	Thomson River	0.73	0.78	0.64	0.68	0.71
225219	Macalister River @ Glencairn	Thomson River	0.8	0.81	0.42	0.53	0.64
225230	Glenmaggie Creek @ The Gorge	Thomson River	0.75	0.8	0.67	0.71	0.73

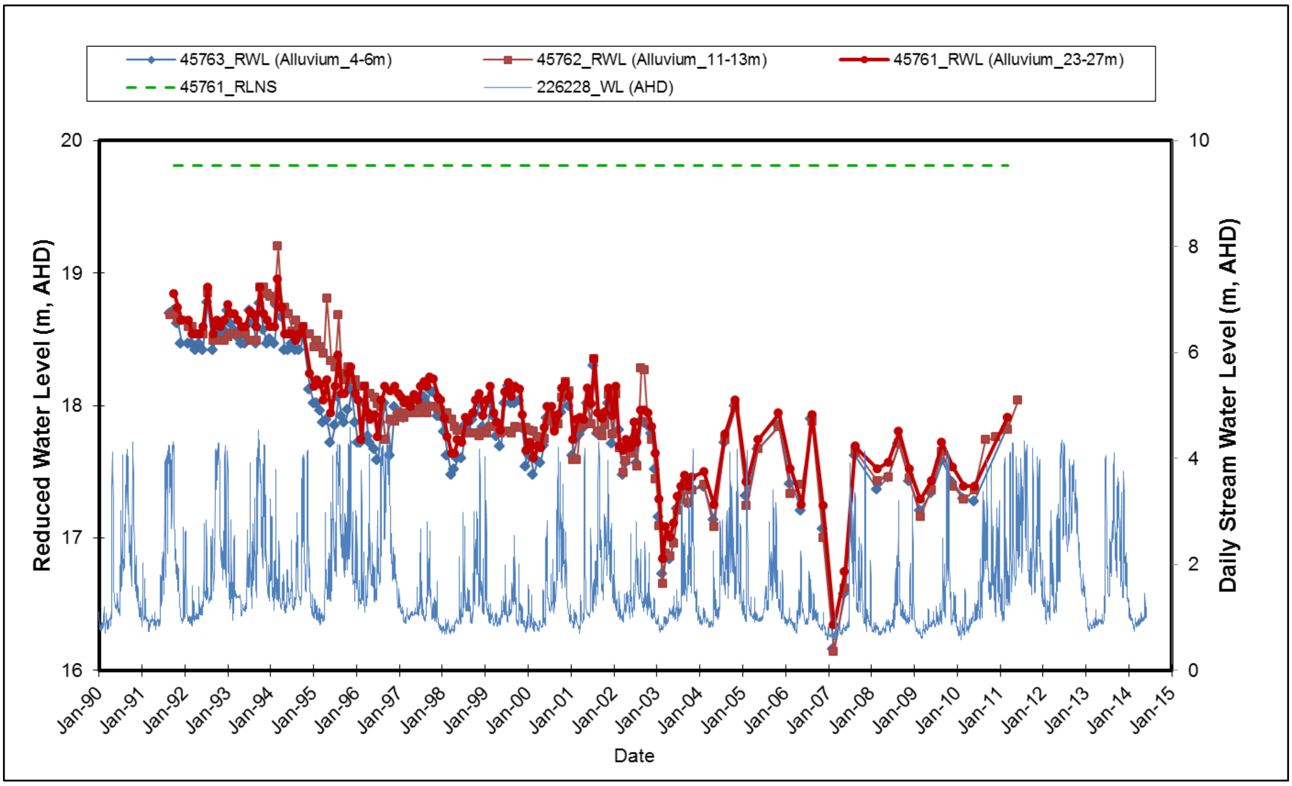


Figure 125 Groundwater hydrographs of three nested bores located in MID west of Sale plotted against daily stream water level of Latrobe River at Rosedale (gauge station no. 226228)

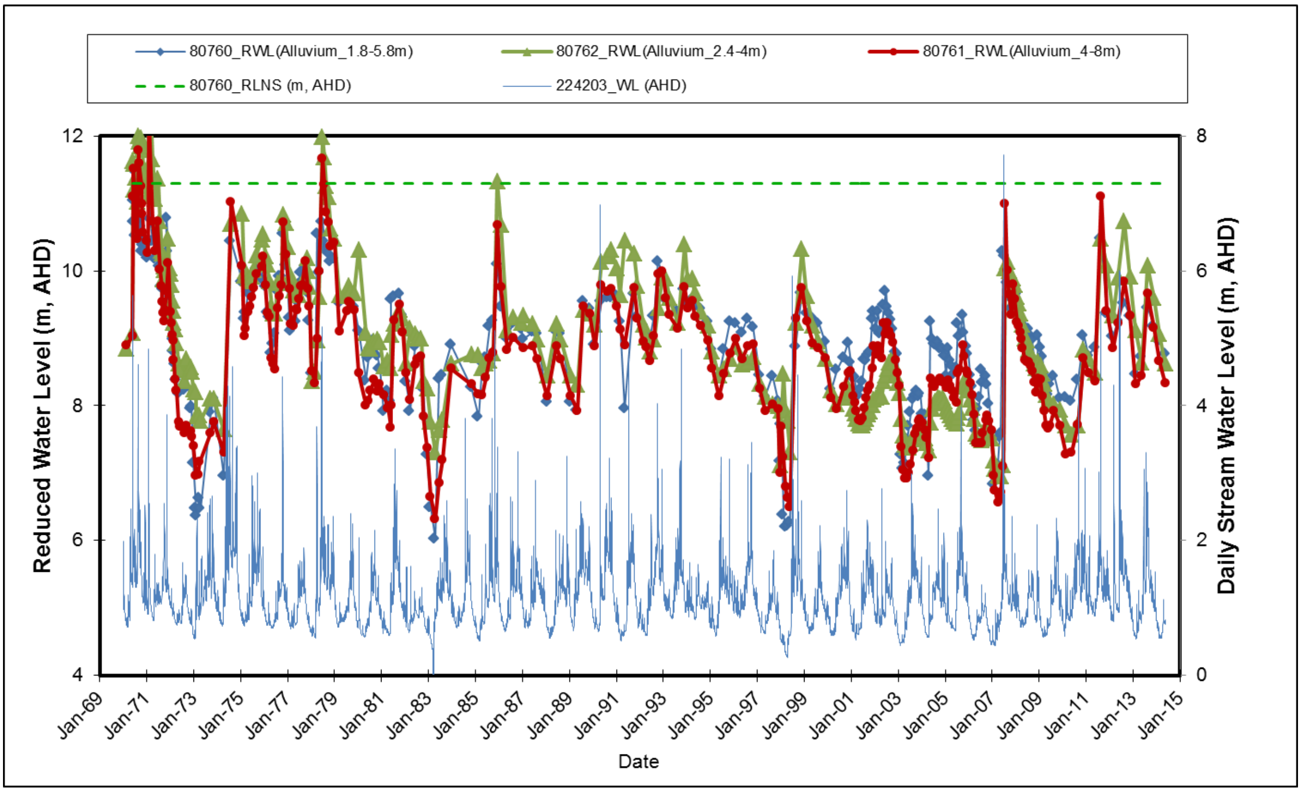


Figure 126 Groundwater hydrographs of a transect of bores located near Mitchell River west of Bairnsdale plotted against daily stream water level of Mitchell River at Rose (gauge station no. 224203)

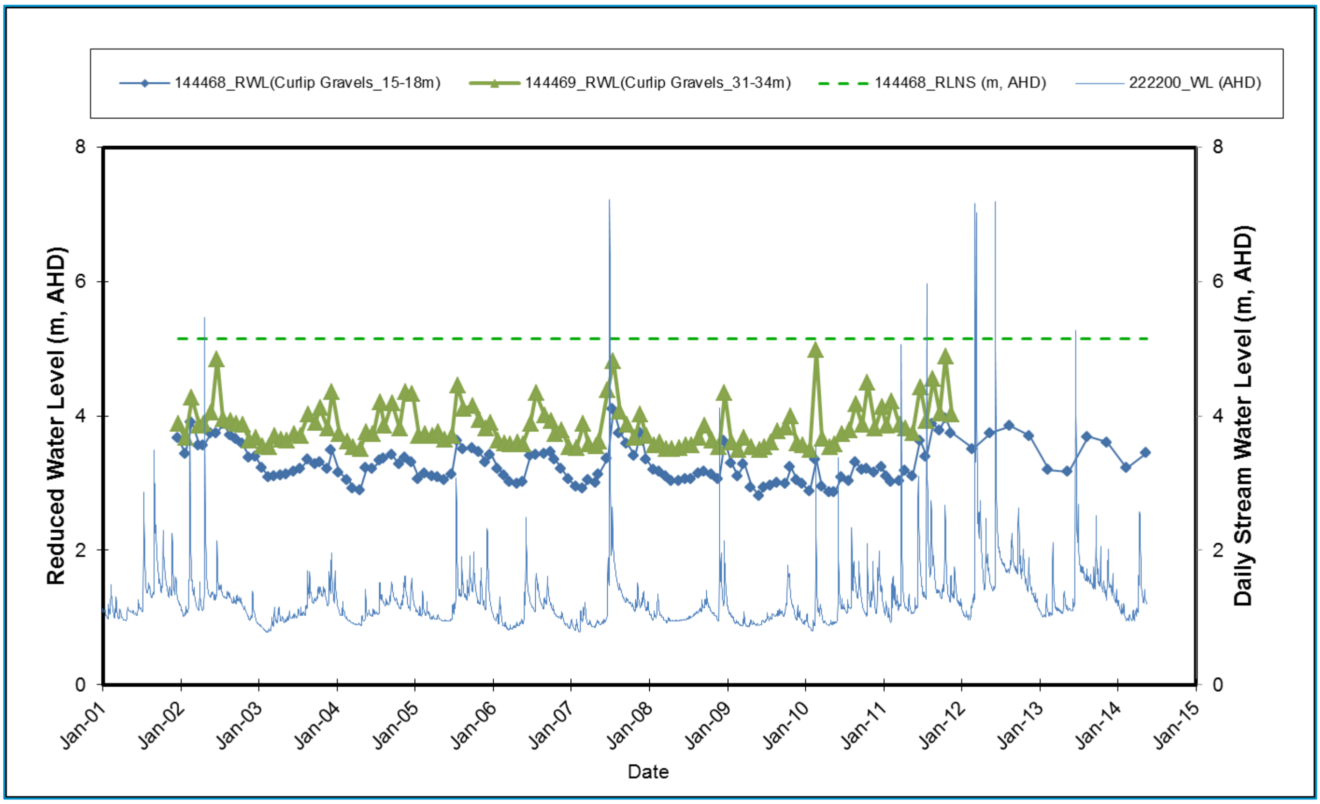


Figure 127 Groundwater hydrographs of two nested bores located near Snowy River west of Orbost plotted against daily stream water level of Snowy River at Jarrahmond (gauge station no. 222200)

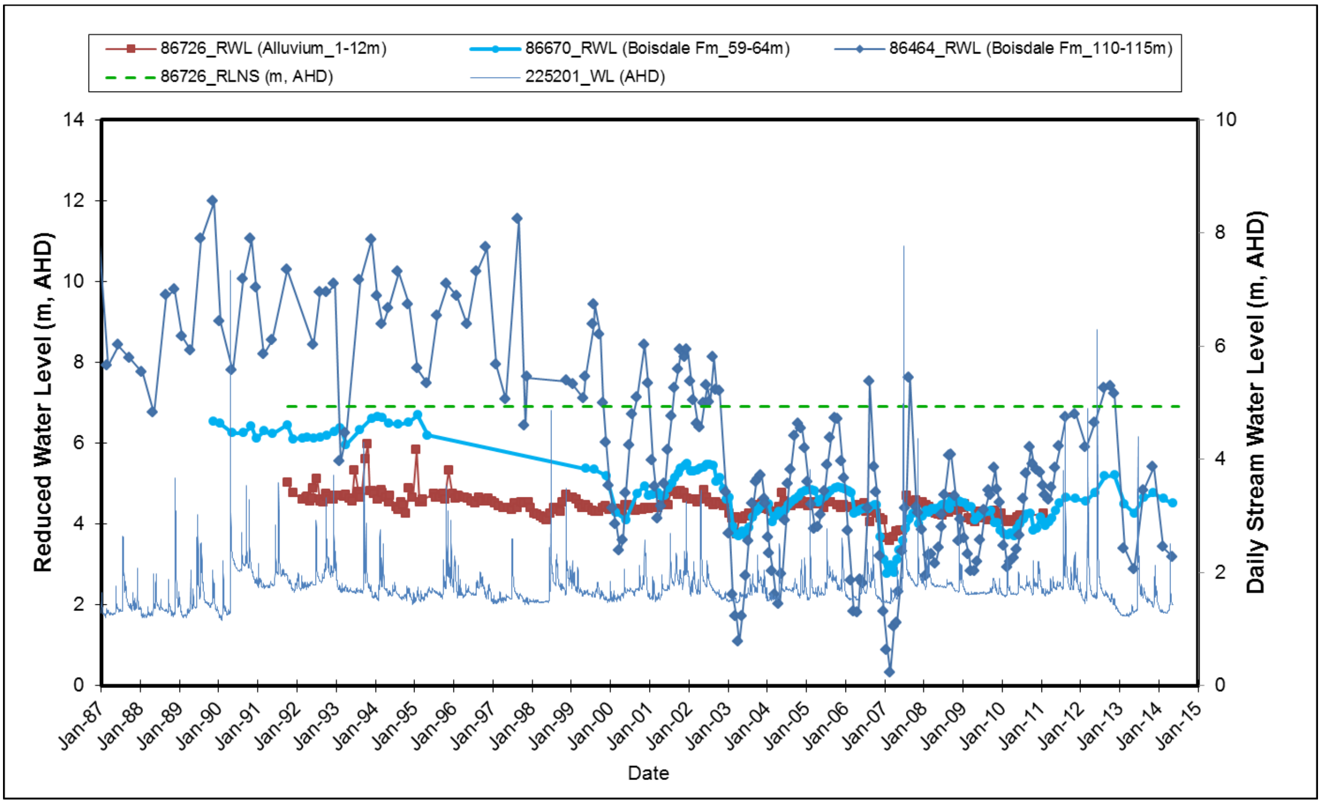


Figure 128 Groundwater hydrographs of three nested bores located in the Macalister Irrigation District north of Sale plotted against daily stream water level of Avon River at Stratford (gauge station no. 225201)

2.6.2.5 Implementation and coal resource development pathway

Summary

The coal resource development pathway (CRDP) consists of expanded open-cut coal operations at Yallourn, Hazelwood and Loy Yang coal mines. The assessment of the implementation of both the CRDP and baseline pathway occurs under a modified future climate scenario.

The spatio-temporal pattern of recharge was computed using the Catchment Analysis Tool (CAT) which accounted for various farming systems. Future climate was scaled seasonally to account for climate change.

Potential evapotranspiration (ET) was based on the difference between daily potential ET calculated from meteorological data and daily vegetative ET estimated from farming system modelling. The extinction depth was based on land use data.

Water extractions accounted for registered bores, mine dewatering, stock and domestic use and offshore production. Mine dewatering was reduced following mine closure.

The rate of coal resource development was set such that mine development was completed by the expected mine closure date.

2.6.2.5.1 Baseline and CRDP climate change signal

The future 90-year climate was based on a trajectory of climate change constructed from the historical January 1983 to December 2012 climate time series. The 1983 to 2012 climate sequence was assumed short enough that a changing climate trend is not significant and assumed to be long enough to be representative of the climate variability (i.e. contains the millennium drought and the floods of 2011). The 30-year historical climate time series was repeated 3 times to create a 90-year time series. The only two forward modelling scenarios that are considered are the baseline and the development pathway. The future 90-year climate time series was used for both simulations to negate the impact of the future climate from the future development upon the assets and receptors.

The future climate series was based on the projections of a single global climate model (GCM) and a single emissions scenario. Climate projections from 15 global climate models (GCMs) were available. Associated with each GCM were local seasonal scaling factors which gave the change in rainfall expected per degree of global warming. The choice of the GCM was based on evaluating each GCM assuming a global warming of 1°C. The resultant average annual rainfall estimates from each GCM for the entire study area were spatially compiled from which the GCM corresponding to the median annual rainfall estimate was selected (Table 21). Based on results summarised in Table 21, the miroc3 GCM pattern of change data was used to seasonally scale 1982 to 2011 rainfall, while all other climate variables remained unchanged. The first block 2012 to 2041 used a global warming of 1°C, the second block 2042 to 2071 used 1.5°C, and the third block from 2072 to 2101 used 2°C.

Table 21 Average annual rainfall estimates for the Gippsland Basin derived using various global climate models assuming a global warming of 1°C

GCM	Average annual rainfall (mm/yr)	% of baseline (historical 1982-2011)
Baseline (historical 1982-2011)	904	100
cccmacgcm31t47	867	95.8
cccmacgcm31t63	901	99.6
cnrmcm3	841	93.0
csiromk3	865	95.7
gfdlcm2	841	93.0
Gissaom	876	96.8
iapfgoals1	890	98.5
inmcm3	875	96.8
ipslcm4	826	91.3
miroc3	874*	96.6
Miubechog	862	95.3
mpiecham5	879	97.2
mricgcm2	866	95.8
ncarccsm3	899	99.4
ncarpcm1	909	100.5

* Identified as the median rainfall estimate.

2.6.2.5.2 Baseline and CRDP recharge

For the baseline and coal resource development pathway (CRDP) simulations, recharge was estimated using the Catchment Analysis Tool (CAT) (Beverly et al., 2005; Beverly, 2009) under the future climate pattern scaled seasonally to account for climate change. The CAT landscape model comprises a suite of farming system models to simulate soil-water-plant interactions in the unsaturated zone. Daily water balance estimates were derived for the period 1970 to 2102 using a combination of historical and future climate conditions from which recharge was spatially assigned to the groundwater model. Although the CAT model accounts for elevated carbon dioxide impacts on plant performance, this was not considered in the current study.

2.6.2.5.3 Baseline and CRDP evapotranspiration

Potential groundwater evapotranspiration (ET) was based on the water balance estimates derived using the Catchment Analysis Tool (CAT) (Beverly et al., 2005; Beverly, 2009) and as used to derive recharge estimates under the future climate patterns (refer to above). The maximum evapotranspiration rate was calculated as the difference between potential daily ET and estimated daily vegetative ET as predicted using the CAT modelling framework. This approach ensures that the sum of estimated daily vegetative ET from the unsaturated zone and the assigned maximum groundwater ET from the saturated zone cannot exceed daily potential ET calculated from meteorological data.

The groundwater ET extinction depth that defines the water table depth (below natural surface below which no ET will occur) was based on the vegetation root depth assigned in the various farming system models used to estimate recharge within the CAT modelling framework as reported in Beverly et al. (2015). The extinction depths vary from 800 mm for annual pasture to 7 m for forests.

2.6.2.5.4 Baseline extractions

The groundwater model incorporated 1569 registered bores, 118 mine dewatering pumps, 53,245 stock and domestic bores and 22 offshore production bores. The predictive modelling applied the baseline extraction volumes for operational developments as of December 2012.

2.6.2.5.5 CRDP extractions

The predictive modelling from January 2013 to December 2102 applied the 2010 to 2011 extraction volumes year-on-year with the exception of the mine dewatering pumps. The extraction volumes assigned to mine pumps applied the 2007 to 2008 annual volume distributed evenly across each month until the expected mine closure date, after which the volume was progressively reduced according to the following criteria:

- Yallourn mine pumps: cease all pumping post-December 2032
- Hazelwood mine pumps: maintain 2013 extractions until December 2036 after which extractions are reduced pro-rata over the remaining modelling period with a target date to cease pumping in 2123
- Loy Yang mine pumps: maintain 2013 extractions until December 2048 after which extractions are reduced pro-rata over the remaining modelling period with a target date to cease pumping in 2123.

It must be stressed that the mine rehabilitation scenario described above is hypothetical and is not based on consultation with the appropriate water supply regulator. As such, it does not imply a preferred or intended rehabilitation strategy.

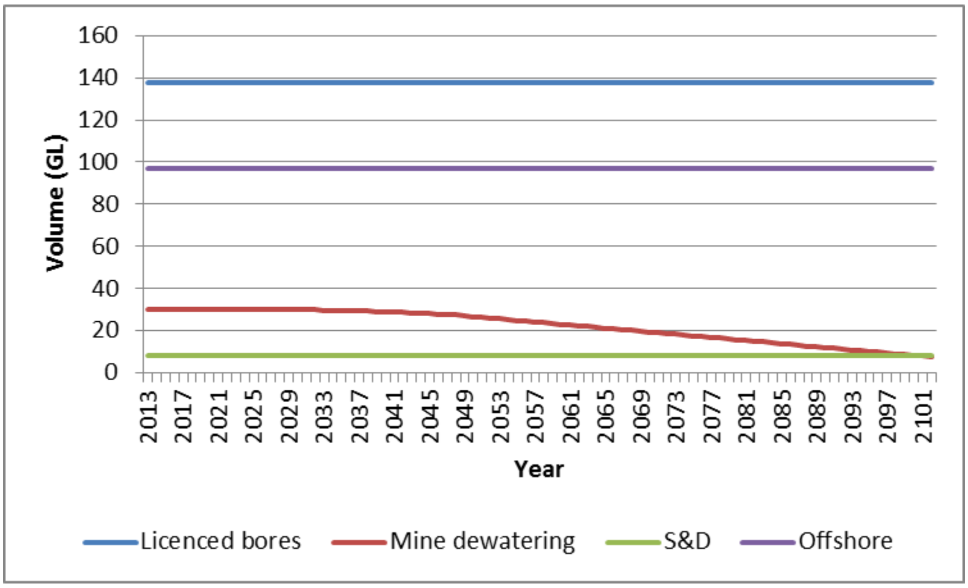


Figure 129 **Groundwater extractions applied to the model for 2013 to 2102**

2.6.2.5.6 CRDP mine development

As reported in Section 2.3.4.1 of the Conceptual Modelling report (product 2.3) for the Gippsland Basin bioregion, the development pathways of three coal mines are considered in the Gippsland Basin numerical model relating to the Yallourn Coal Field Development Project, the Hazelwood West Field Project and future mining blocks within the current Loy Yang Project. The planned development of these mines is described in Section 1.2.3 of the Coal and Coal Seam Gas Resource Assessment (product 1.2) for the Gippsland Basin bioregion.

The modelling assumed that the expansion of existing open-cut mine pits occurs in a sequenced and progressive lateral direction. The progressive development stages were based on mine work plans and broadly adopted the following pathways:

- Yallourn Coal Field Development Project: expand the existing void in a south-easterly direction
- Hazelwood West Field Project: expand the existing void in a westerly direction
- Loy Yang: expand in a north easterly direction and then travel in a southerly direction to align with the southern boundary of the extraction limit.

The rate of development was set such that mine development was completed by the expected mine closure date. Drain cells were used to simulate mine voids so as to enforce outflows from the groundwater model. The base of each drain cell was set to the base of the coal seam less 10 metres, where the coal seams of interest were the Yallourn Seam, Morwell interseams and the M2A sequence for the Yallourn, Hazelwood and Loy Yang mines respectively. The drain conductance’s were set to ensure inactive cells above the modelled layer representing the base of the void and set to the lateral conductivity of the coal seam in that layer representing the base of the void. Drain volumes within the void were compared for consistency to existing mine dewatering extractions.

2.6.2.6 Parameterisation

Summary

The regional groundwater model simulates 30 modelled layers representing key aquifers, aquitards and coal seams. There are up to four key hydraulic parameters associated with each modelled layer. The attribution of modelled groundwater layers were initially based on reported parameter ranges and then subsequently refined based on a spilt transient calibration/verification approach in which parameter optimisation was applied from 1990 to 2000 following which verification was undertaken over the subsequent 11 years from 2001 to 2012.

Initial parameter ranges presented in Table 22 are sourced from literature and previous numerical modelling and show that there is considerable variability in both the hydraulic conductivity and storage estimates. Initial model parameter attribution is also summarised in Table 22; this attribution is based upon the perceived likely value of the aquifer based upon the pre-existing studies cited. Initial model parameters are based on the average aquifer values, and by definition within the range cited, for the particular hydrogeological unit that the layer represents.

The depositional history of the basin is dominated by fluvial, deltaic, marginal marine and open marine environments (Schaeffer, 2008, after others). Typically, vertical hydraulic conductivity (Kz) is approximated as an order of magnitude less than horizontal hydraulic conductivity (Kxy), and as an initial calibration value, Kz values were set to 0.1 of the Kxy value, and the final, calibrated, value of this ratio is provided in Table 23.

The groundwater model calibration was based on a spilt transient calibration/verification approach in which parameter optimisation was applied from 1990 to 2000 following which verification was assessed over the subsequent 11 years from 2001 to 2012. Computational constraints impacted on the progress of the transient calibration. The calibration strategy was to produce modelled hydrographs that match the trends of the observation bores. It was acknowledged that any elevation offsets between observed and predicted heads would be addressed as part of future model refinement.

With the exception of zones 23–29 representing the Strzelecki Formation parameterisation, the post-calibration modelled aquifer parameterisation is summarised in Table 23. The aquifer parameterisation attributed to zones 23–29 were revised following a review of the Strzelecki Formation parameterisation. The model calibration results in the horizontal hydraulic conductivity for the uppermost Strzelecki units of the order 0.195 m/day and the vertical hydraulic conductivity of 0.0295 m/day which are inconsistent with the potential for this layer to act as a tight or shale gas reservoir. In order to better represent this potential, a lower value was used for scenario purposes. The spatial variability of key aquifer parameters for modelled layers 2 (the Quaternary deposits), 9 (lower M2 interseam), 18 (the Upper Latrobe Group), 19 (the T1 coal seam) and 24 (the Strzelecki 500–1000 m) are shown in Figure 130 to Figure 143 inclusive.

Table 22 Range and value of specific yield (Sy), specific storage (Ss) and lateral hydraulic conductivity (Kxy) initially assigned to each modelled layer in the Gippsland model

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
1			Marine water thickness	N/A	N/A	N/A	(1.0×10^{-5})	(1.0)	(100)	Initial values in this study
2	101		Quaternary	Various Aeolian deposits, various fluvial, lacustrine, alluvial and colluvial sediments	1	UC	2.5×10^{-5}	0.15	0.01 to 10.26	Schaeffer (2008)
							0.02 to 0.05	0.04 to 0.08	0.1 to 1	GHD (2008a, 2008b)
							1.0×10^{-5} to 1.0×10^{-4}	0.04 to 0.25	2 to 50	GHD (2010a, 2010b)
							N/A	0.001 to 0.05	1.0×10^{-6} to 100	Dahlhaus et al. (2004)
							2.4×10^{-6}	N/A	59	Mollica (1991)
							(1.0×10^{-5})	(0.07)	(2.0)	Initial values in this study
3	102		Haunted Hill Formation	Haunted Hill Formation, Eagle Point Sand	1	UC	1.0×10^{-5}	0.1 to 0.15	0.01 to 10.26	Schaeffer (2008)
							0.02 to 0.05	0.04 to 0.08	1 to 10	GHD (2008a, 2008b)
							0.01	0.1	2 to2.01	GHD (2010a; 2010b)
							N/A	0.001 to 0.05	1.0×10^{-6} to 100	Dahlhaus et al. (2004)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m⁻¹) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							(1.0 X 10^{-5})	(0.1)	(2.01)	Initial values in this study
4	103		Nuntin clay	Boisdale Fm (Nuntin Clay), Jemmys Point Fm Sale Grp	1	C/UC	1.0 X 10^{-6} to 1.0 X 10^{-5}	0.005 to 0.1	0 to 0.5	Schaeffer (2008)
							0.001	0.02	0.2 to 0.5	GHD (2008a, 2008b)
							0.01	0.1	0.1 to 0.23	GHD (2010a, 2010b)
							(1.0 X 10^{-6})	(0.04)	(0.23)	Initial values in this study
5	105		Boisdale Formation	Boisdale Fm (Wurruk Sand), Jemmys Point Fm, Unnamed Tertiary Sands, Gravels and Clays	1	C/UC	1.0 X 10^{-5} to 1.0 X 10^{-3}	0.1 to 0.2	1 to 30	Schaeffer (2008)
							N/A	N/A	5.31	Nahm (1977)
							N/A	N/A	6.5	Nahm & Reid (1979a)
							N/A	0.1	0.1 to 1	SKM (1999)
							1.0 X 10^{-4}	N/A	5 to 24	Walker and Mollica (1990)
							0.001	0.02	15 to 25	GHD (2008a, 2008b)
							0.01	0.1	2 to 12.38	GHD (2010a, 2010b)
							1.0 X 10^{-4} to 5.0 X 10^{-4}	N/A	4.7 to 13	SKM (2006)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							(1.0×10^{-4})	(0.1)	(12.38)	Initial values in this study
6	106		Jemmy's Point Formation and upper Hazelwood Formation	Jemmy's Point Formation and upper Hazelwood Formation	1	C/UC	1.0×10^{-5} to 5.0×10^{-4}	0.1 to 0.2	0.2 to 13	Schaeffer (2008)
							0.001	0.02	0.2 to 0.5	GHD (2008a, 2008b)
							1.0×10^{-6} to 1.0×10^{-5}	0.1	2 to 10	GHD (2010a; 2010b)
							(2.0×10^{-5})	(0.1)	(0.23)	Initial values in this study
7	106	Yallourn Coal Seam	Y, Y1a, Y1b, Y2, Y1; y_all	Yallourn Formation	2	C/UC (Aquitard)	2.5×10^{-5} to 2.1×10^{-4}	0.001 to 0.05	2.0×10^{-6} to 0.1	Schaeffer (2008)
							N/A	N/A	0.005	Brumley et al. (1981)
							0.0001	0.005	0.04	Aquaterra (2008)
							N/A	N/A	0.015 to 0.1	PDA (2006)
							N/A	N/A	6×10^{-5} to 1.8×10^{-1}	Harlow & LeCain (1993)
							3.0×10^{-6} to 5.0×10^{-4}	N/A	0.0005 to 1.36	USQ (2011)
							(2.0×10^{-5})	(0.02)	(0.0002)	Initial values in this study
8	106	Yallourn Aquifer & interseam	Hazelwood Formation; all floor & M1a_all top	Hazelwood Formation, Yallourn Formation	3	C/UC	1.0×10^{-6} to 2.5×10^{-5}	0.05 to 0.1	0.2 to 8	Schaeffer (2008)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							0.001	0.02	0.2 to 0.5	GHD (2008a, 2008b)
							0.01	0.1	2 to 2.44	GHD (2010a, 2010b)
							1.0×10^{-4}	0.1	0.2 to 0.5	SKM (1999)
							6.8×10^{-5}	N/A	8	Blake (1972)
							(1.0×10^{-5})	(0.1)	(2.44)	Initial values in this study
9	107, 108	Lower M2 interseam	Balook Formation Tambo River, Wuk Marl, Gippsland Limestone,	Balook Fm, LVG: Yarragon Fm, Alberton Fm, Tambo River Fm, Gippsland Limestone, Middle Lakes Entrance Fm	5, 9	C/UC	1.0×10^{-6} to 1.0×10^{-4}	0.04-0.06	2 to 57	Schaeffer (2008)
							0.0008	0.05	1.5 to 2	GHD (2008a, 2008b)
							0.01	0.1	1 to 7.5	GHD (2010a, 2010b)
							N/A	N/A	10 to 58	Reid (1985)
							1.0×10^{-5}	0.06	1	Golder Associates (1990)
							1.0×10^{-4}	0.1	0.5 to 8	SKM (1999)
							N/A	N/A	2 to 7	Brumley et al. (1981)
							1×10^{-5} to 09.0×10^{-4}	N/A	2 to 30	Walker & Mollica (1990)
							(5.0 X 10-6)	(0.05)	(3.53)	Initial values in this study

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
10		M1A coal	Yarragon Formation, M10, M1a, M1b2, ML, M12; M1a_all	Yarragon Formation, Upper Gippsland Limestone	4	C/UC (Aquitard)	1.0×10^{-5} to 1.0 X 10-4	0.001 to 0.05	2.0×10^{-6} to 0.1	Schaeffer (2008)
							N/A	N/A	0.015 to 0.1	PDA (2006)
							0.0001	0.005	0.04	Aquaterra (2008)
							N/A	N/A	6×10^{-5} to 1.8×10^{-1}	Harlow & LeCain (1993)
							3.0×10^{-6} to 5.0×10^{-4}	N/A	0.0005 to 1.36	USQ (2011)
							(1.0×10^{-5})	(0.02)	(0.0005)	Initial values in this study
11		Morwell 1A interseam/aquifer	M1a_all_floor & M1b_top	Morwell Formation, Middle Gippsland Limestone	5	C/UC	1.0×10^{-6} to 1.0×10^{-4}	0.05 to 0.1	7.7×10^{-5} to 8	Schaeffer (2008)
							0.0002	0.02	0.04 to 0.05	GHD (2008a, 2008b)
							0.01	0.1	2 to 2.44	GHD (2010a; 2010b)
							1.0×10^{-4}	0.1	0.28 to 0.5	SKM (1999)
							1.2×10^{-5}	N/A	0.27	Nahm (1972)
							(5.0×10^{-6})	(0.1)	(2.44)	Initial values in this study

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
12		Morwell 1B coal	M1b, M1b1, M1b2, ML, M12	Morwell Formation / Morwell seams, Lower Gippsland Limestone	6	C/UC (Aquitard)	1.0 X 10^{-6} to 5.0 X 10^{-4}	0.001-0.05	2.0 X 10^{-6} to 0.1	Schaeffer (2008)
							0.0002	0.02	0.04-0.05	GHD (2008a, 2008b)
							N/A	N/A	0.0001	Brumley et al. (1981)
							N/A	N/A	0.015 to 0.1	PDA (2006)
							0.0001	0.005	0.04	Aquaterra (2008)
							N/A	N/A	6 X 10^{-5} to 1.8 X 10^{-1}	Harlow & LeCain (1993)
							3.0 X 10^{-6} to 5.0 X 10^{-4}	N/A	0.0005 to 1.36	USQ (2011)
							(5.0 X 10-6)	(0.05)	(0.0015)	Initial values in this study
13		Morwell 1B interseam	Floor M1b_all & M2_all top	Morwell Formation / Morwell seams, Upper Lakes Entrance Formation	7	C/UC	9.35 X 10^{-9} to 1 X 10^{-4}	0.06-0.1	2.3 X 10^{-4} to 40.39	Schaeffer (2008)
							0.0002	0.02	0.04-0.05	GHD (2008a, 2008b)
							0.01	0.1	0.97-1	GHD (2010a, 2010b)
							1.0 X 10^{-6} to 9.4 X 10^{-9}	N/A	0.08 to 4.07	Nahm (1977)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							0.003	N/A	2.5	Brumley et al. (1981)
							0.001	N/A	10.83	Fraser (1980)
							N/A	N/A	4.48 to 47.68	Barton (1971)
							1.0×10^{-6} to 1.0×10^{-4}	N/A	2 to 7	Thatcher (1976)
							2.5×10^{-5}	0.06	0.2 to 5	Golder Associates (1990)
							1.0×10^{-4}	0.1	0.5 to 8	SKM (1999)
							N/A	N/A	6.91	Golder Brawner (unpubl. data)
							(4.0×10^{-6})	(0.1)	(0.97)	Initial values in this study
14		Morwell 2	M2, M2A, M2B coal; M2_all	Morwell Formation / Morwell seams / Middle Lakes Entrance Formation	8, 10	C/UC (Aquitard)	8.8×10^{-7} to 9.2×10^{-4}	0.001 to 0.05	1.0×10^{-5} to 0.1	Schaeffer (2008)
							0.0002	0.02	0.04 to 0.05	GHD (2008a, 2008b)
							0.01	0.1	0.1 to 0.42	GHD (2010a, 2010b)
							N/A	N/A	0.015 to 0.1	PDA (2006)
							0.0001	0.005	0.04	Aquaterra (2008)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							N/A	N/A	6×10^{-5} to 1.8×10^{-1}	Harlow and LeCain (1993)
							3.0×10^{-6} to 5.0×10^{-4}	N/A	0.0005 to 1.36	USQ (2011)
							(1.0×10^{-5})	(0.02)	(0.42)	Initial values in this study
15	108		Lakes Entrance Formation	Lakes Entrance Fm /Morwell Formation	8, 10, 12	C/UC (Aquitard)	3.4×10^{-7} to 1.0×10^{-4}	0.001 to 0.05	1.0×10^{-5} to 0.1	Schaeffer (2008)
							0.0002	0.02	0.04 to 0.05	GHD (2008a, 2008b)
							0.01	0.1	0.1 to 0.42	GHD (2010a; 2010b)
							N/A	N/A	0.03	Thatcher (1976)
							(1.0×10^{-5})	(0.02)	(0.05)	Initial values in this study
16	109		M2c aquifer/ Seaspray Sands	LVG: M2C aquifer, Seaspray Sand, Lower Lakes Entrance Fm, Seaspray Sands	11, 13	C/UC	1×10^{-6} to 4.7×10^{-4}	0.03 to 0.1	6.4×10^{-4} to 76.06	Schaeffer (2008);
							0.0008	0.05	1.5 to 2	GHD (2008a, 2008b)
							0.01	0.1	0.1 to 1.91	GHD (2010a, 2010b)
							6.3×10^{-6} to 2.2×10^{-5}	N/A	2 to 48	Nahm (1973a, 1973b, 1977)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							4.0 X 10^{-4}	N/A	5.7 to 32.35	Brumley et al. (1981)
							5.0 X 10^{-5} to 2.5 X 10^{-4}	N/A	0.1 to 1.11	Thatcher (1976)
							N/A	N/A	0.22 to 19.38	Geo-Eng (1993, 1996, 2001)
							N/A	N/A	7.49	Reid (1985)
							N/A	N/A	23.23	Barton (1971)
							1.0 X 10^{-5} to 1.0 X 10^{-3}	0.015 to 0.06	0.2 to 8	Golder Associates (1990)
							1.0 X 10^{-4}	0.1	0.5 to 8	SKM (1999)
							3.0 X 10^{-4}	N/A	13.6	Fraser (1980)
							(3.0 X 10^{-5})	(0.1)	(1.63)	Initial values in this study
17	112		Thorpdale volcanics	Thorpdale Volcanics	7, 9, 11	C/UC	1.0 X 10^{-6} to 4.7 X 10^{-4}	0.015 to 0.1	0.03 to 6.4	Schaeffer (2008)
							0.04	0.05	0.2 to 1	GHD (2008a, 2008b)
							0.01	0.1	0.51 to 2	GHD (2010a, 2010b)
							5.0 X 10^{-5} to 2.5 X 10^{-4}	N/A	0.1 to 1.11	Thatcher (1976)
							1.7 X 10^{-7} to 3.5 X 10^{-5}	N/A	7.49 to 23.6	Reid (1985a; 1985b)
							1.0 X 10^{-5} to 1.0 X 10^{-3}	0.015 to 0.06	0.2 to 8	Golder Associates (1990)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							1.0 X 10^{-4}	0.1	8	SKM (1999)
							6.3 X 10^{-6} to 2.2 X 10^{-5}	N/A	2 to 48	Nahm & Reid (1979a, 1979b)
							N/A	<0.05	0.001 to 100	Dahlhaus et al. (2004)
							5.0 X 10^{-5}	N/A	6 to 35.6	Pratt (1985)
							(1.0 X 10^{-5})	(0.1)	(0.51)	Initial values in this study
18	111		Upper Latrobe Group	Childers Fm, M2 / M2C aquifer (when basal aquifer)	13	C/UC	1.0 X 10^{-5} to 5.6 X 10^{-2}	0.03 to 0.1	1.6 X 10^{-3} to 32.35	Schaeffer (2008)
							0.04	0.05	0.2 to 1	GHD (2008a, 2008b)
							0.01	0.1	0.76	GHD (2010a, 2010b)
							1.5 X 10^{-6} to 4.0 X 10^{-5}	N/A	1 to 13.84	Brumley et al. (1981)
							1.0 X 10^{-5} to 1.1 X 10^{-4}	N/A	0.25 to 7.3	Thatcher (1976)
							N/A	N/A	2.34 to 76.06	Geo-Eng (1993, 1996b, 2001)
							1.7 X 10^{-7} to 3.5 X 10^{-5}	N/A	7.49 to 23.6	Reid (1985a, 1985b)
							1.0 X 10^{-4} to 1.0 X 10^{-3}	0.015 to 0.06	0.8 to 8	Golder Associates (1990)
							1.0 X 10^{-4}	0.1	8	SKM (1999)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							3.0×10^{-4}	N/A	13.6	Fraser (1980)
							N/A	N/A	2.0	Nahm (1974)
							6.3×10^{-6} to 2.2×10^{-5}	N/A	2 to 48	Nahm & Reid (1979a, 1979b)
							5.0×10^{-5}	N/A	6 to 35.6	Pratt (1985)
							(1.0 X 10-4)	(0.1)	(1.63)	Initial values in this study
19	111	T1 coal	TP, T1, TRU, TRM, TRL	Traralgon Fm/ Burong Fm, Carrajung Volcanics	14	C/UC (Aquitard)	2.9×10^{-7} to 6.9×10^{-5}	0.001 to 0.05	1×10^{-6} to 5.0×10^{-3}	Schaeffer (2008)
							N/A	N/A	0.015 to 0.1	PDA (2006)
							3.0×10^{-6} to 5.0×10^{-4}	N/A	0.0005 to 1.36	USQ (2011)
							0.0001	0.005	0.04	Aquaterra (2008)
							N/A	N/A	6×10^{-5} to 1.8×10^{-1}	Harlow & LeCain (1993)
							(1.0×10^{-5})	(0.02)	(0.0025)	Initial values in this study
20	111	T1 interseam	Floor T1_all & Top T2_all	Traralgon Fm/ Burong Fm	15	C/UC	2.5×10^{-6} to 9.8×10^{-4}	0.015 to 0.1	1.6×10^{-3} to 48.26	Schaeffer (2008)
							0.04	0.05	1.1 to 2	GHD (2008a, 2008b)
							0.01	0.1	1 to 2.02	GHD (2010a, 2010b)
							1.0×10^{-6}	N/A	4.07	Nahm (1977)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							1.0×10^{-6} to 7.5×10^{-6}	N/A	1.1 to 6.83	Nahm & Reid (1979b, 1979c, 1979d, 1979e)
							2.5×10^{-5} to 4.0×10^{-4}	N/A	2 to 88	Brumley et al. (1981)
							N/A	N/A	6.33 to 48.26	Geo-Eng (1993, 2001)
							1.0×10^{-4} to 5.0×10^{-4}	0.015 to 0.06	3 to 10	Golder Associates (1990)
							1.0×10^{-4}	0.1	8	SKM (1999)
							(1.0×10^{-4})	(0.1)	(2.02)	Initial values in this study
21	111	T2 coal		Traralgon Fm/ Burong Fm	16	C/UC (Aquitard)	1.7×10^{-7} to 2.4×10^{-5}	0.001 to 0.05	1×10^{-6} to 5×10^{-3}	Schaeffer (2008)
							8.30×10^{-7} to 5×10^{-6}	N/A	1.1×10^{-6} to 3.56×10^{-6}	SKM (2001)
							N/A	N/A	0.015 to 0.1	PDA (2006)
							3.0×10^{-6} to 5.0×10^{-4}	N/A	0.0005 to 1.36	USQ (2011)
							0.0001	0.005	0.04	Aquaterra (2008)
							N/A	N/A	6×10^{-5} to 1.8×10^{-1}	Harlow & LeCain (1993)
							(1.0 X 10-5)	(0.02)	(0.0025)	Initial values in this study

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
22	111	T2 interseam	Lower Latrobe Group; T2_all floor	Lower Latrobe Group; T2_all floor & Traralgon Fm/Burong Fm, Honeysuckle Gravels, Yarram Fm	17	C/UC	1.1 X 10^{-7} to 4.9 X 10^{-5}	0.015 to 0.1	1.6 X 10^{-7} to 24.65	Schaeffer (2008)
							0.04	0.05	1.1 to 2	GHD (2008a, 2008b)
							0.01	0.1	1 to 2.02	GHD (2010a, 2010b)
							1.0 X 10^{-5} to 4.0 X 10^{-4}	N/A	4.27 to 88	Brumley et al. (1981)
							1.0 X 10^{-6}	N/A	4.02	Thompson (1968)
							1.0 X 10^{-4}	0.1	8	SKM (1999)
							(7.0 X 10^{-6})	(0.1)	(2.02)	Initial values in this study
23	114		Strzelecki 500 m; >0–500 m		18	C/UC	4.5 X 10^{-6} to 1.0 X 10^{-5}	N/A	1 X 10^{-10} to 1.0 X 10^{-5}	Schaeffer (2008)
							<3 X 10^{-6} to 5 X 10^{-3}	0.03 to 0.1	2.6 X 10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004-0.005	0.005-0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a; 2010b)
							N/A	0.02 to 0.1	1.0 X 10^{-4} to 1	Dahlhaus et al. (2004)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m⁻¹) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							2.2×10^{-5}	N/A	0.02 to 1	Shugg & Harris (1975)
							3.6×10^{-5}	N/A	0.3	Szabo (1979)
							(1.0×10^{-6})	(0.02)	(0.002)	Initial values in this study
24	114		Strzelecki 500 m; 500–1000 m		18	C/UC	4.5×10^{-6} to 1×10^{-5}	N/A	1×10^{-10} to 1×10^{-5}	Schaeffer (2008)
							<3×10^{-6} to 5×10^{-3}	0.03 to 0.1	2.6×10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004-0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a; 2010b)
							(1.0×10^{-6})	(0.02)	(0.002)	Initial values in this study
25	114		Strzelecki 1 km; 1000–2000 m		18	C/UC	4.5×10^{-6} to 1×10^{-5}	N/A	1×10^{-10} to 1×10^{-5}	Schaeffer (2008)
							<3×10^{-6} to 5×10^{-3}	0.03 to 0.1	2.6×10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004 to 0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a, 2010b)
							(1×10^{-6})	(0.02)	(0.0004)	Initial values in this study

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
26	114		Strzelecki 1 km; 2000–3000 m		18	C/UC	4.5 X 10^{-6} to 1.0 X 10^{-5}	N/A	1 X 10^{-10} to 1 X 10^{-5}	Schaeffer (2008)
							<3 X 10^{-6} to 5 X 10^{-3}	0.03 to 0.1	2.6 X 10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004 to 0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a, 2010b)
							(1.0 X 10^{-6})	(0.02)	(0.0004)	Initial values in this study
27	114		Strzelecki 1km; 3000-4000m		18	C/UC	4.5 X 10^{-6} to 1 X 10^{-5}	N/A	1 X 10^{-10} to 1 X 10^{-5}	Schaeffer (2008)
							<3.0 X 10^{-6} to 5.0 X 10^{-3}	0.03 to 0.1	2.6 X 10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004 to 0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a, 2010b)
							(1.0 X 10^{-6})	(0.02)	(0.0004)	Initial values in this study
28	114		Strzelecki 1km; 4000-6000m		18	C/UC	4.5 X 10^{-6} to 1.0 X 10^{-5}	N/A	1 X 10^{-10} to 1 X 10^{-5}	Schaeffer (2008)
							<3 X 10^{-6} to 5 X 10^{-3}	0.03 to 0.1	2.6 X 10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004 to 0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a, 2010b)
							(1.0 X 10^{-6})	(0.01)	(0.0004)	Initial values in this study
29			Strzelecki 4km; >6000m		18	C/UC	4.5 X 10^{-6} to 1.0 X 10^{-5}	N/A	1 X 10^{-10} to 1 X 10^{-5}	Schaeffer (2008)
							<3 X 10^{-6} to 5 X 10^{-3}	0.03 to 0.1	2.6 X 10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)
							N/A	N/A	0.001 to 0.3	Leonard (2006)
							0.00004 to 0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)
							0.01	0.02	0.0001 to 0.008	GHD (2010a, 2010b)
							(1 X 10^{-6})	(0.01)	(0.0004)	Initial values in this study
30			Palaeozoic basement 200m thick		18	4.5 X 10^{-6} to 1 X 10^{-5}	N/A	1 X 10^{-10} to 1 X 10^{-5}	Schaeffer (2008)	4.5 X 10^{-6} to 1 X 10^{-5}
						<3 X 10^{-6} to 5 X 10^{-3}	0.03 to 0.1	2.6 X 10^{-9} to 2.6	Domenico & Schwartz (1990); Batu (1998); Todd (1980)	<3 X 10^{-6} to 5 X 10^{-3}
						N/A	N/A	0.001 to 0.3	Leonard (2006)	N/A

Model layer	VAF no.	Coal name	Comment	VAF HGU	Layers (Schaeffer 2008)	Aquifer type[1]	Ss (m^{-1}) [2,3]	Sy[2,3]	Kxy (m/d) [2,3]	Reference
						0.00004 to 0.005	0.005 to 0.02	0.001 to 0.008	GHD (2008a, 2008b)	0.00004 to 0.005
						0.01	0.02	0.0001 to 0.008	GHD (2010a; 2010b)	0.01
						(1 X 10^{-6})	(0.02)	(0.0004)	Initial values in this study	(1 X 10^{-6})

1. UC = unconfined, C/UC = confined/unconfined.
2. The ranges of aquifer parameter values were obtained from the publications listed in the table.
3. The aquifer parameter values in bracket are the initial values for the groundwater model in the study. They are primarily sourced from the previously calibrated groundwater models.
4. A Kx to Kz ratio of 10:1 was assumed prior to calibration

Table 23 Calibrated model aquifer parameterisation

Zone	Aquifer	Kxy (m/d)	Kzz (m/d)	Specific yield	Specific storage (m^{-1})	Kzz/Kxy
1	Marine water thickness	1.063×10^{2}	1.594×10^{1}	0.1	1×10^{-5}	0.150
2	Quaternary	6.507	9.761×10^{-1}	0.1	1×10^{-5}	0.150
3	Haunted Hill Formation	3.203	4.804×10^{-1}	0.1	1×10^{-5}	0.150
4	Nuntin clay	3.333	5×10^{-1}	0.04	1×10^{-5}	0.150
5	Boisdale Formation	2.986×10^{1}	4.479	0.1	1×10^{-5}	0.150
6	Jemmys Point & Upper Hazelwood Formation	8.890×10^{-2}	1.334×10^{-2}	0.1	1×10^{-5}	0.150
7	Yallourn Coal Seam	2×10^{-3}	3×10^{-4}	0.1	1×10^{-5}	0.150
8	Yallourn Aquifer and interseam	7.667×10^{-1}	1.15×10^{-1}	0.1	1×10^{-5}	0.150
9	Lower M2 interseam	1.605×10^{1}	1.202	0.1	1×10^{-5}	0.075
10	M1A coal	2.230×10^{-1}	3.345×10^{-2}	0.02	1×10^{-5}	0.150
11	Morwell 1A interseam/aquifer	7.450	7.45×10^{-1}	0.1	1×10^{-5}	0.100
12	Morwell 1B coal	4.525×10^{-2}	6.79×10^{-3}	0.1	1×10^{-5}	0.150
13	Morwell 1B interseam	9.691	1.602×10^{-1}	0.1	1×10^{-5}	0.017
14	Morwell 2	4.108 X 10-1	6.162×10^{-2}	0.1	1×10^{-5}	0.150
15	Lakes Entrance Formation	9.572×10^{-2}	8.860×10^{-3}	0.05	1×10^{-5}	0.093
16	M2c aquifer/Seaspray sands	6.119	3.902×10^{-1}	0.1	1×10^{-5}	0.064
17	Thorpdale volcanics	6.522×10^{-1}	1.820×10^{-2}	0.1	1×10^{-5}	0.028
18	Upper Latrobe Group	2.350	3.524 X 10-1	0.1	1×10^{-5}	0.150
19	T1 coal	1.92×10^{-3}	2.9×10^{-4}	0.02	1×10^{-5}	0.151
20	T1 interseam	1.262	1.894×10^{-1}	0.1	1×10^{-5}	0.150
21	T2 coal	1.420×10^{-3}	8×10^{-5}	0.02	1×10^{-5}	0.056
22	T2 interseam	8.862×10^{-1}	9.566×10^{-2}	0.1	1×10^{-5}	0.108
23	Strzelecki top 500m	1×10^{-2}	1×10^{-3}	0.02	1×10^{-5}	0.100
24	Strzelecki 500-1000m	2×10^{-4}	1×10^{-5}	0.02	1×10^{-5}	0.050
25	Strzelecki 1km-2km	2×10^{-4}	1×10^{-5}	0.02	1×10^{-5}	0.050
26	Strzelecki 2km-3km	2 X 10-4	1×10^{-5}	0.02	1×10^{-5}	0.050
27	Strzelecki 3km-4km	2×10^{-4}	1×10^{-5}	0.02	1×10^{-5}	0.050

Zone	Aquifer	Kxy (m/d)	Kzz (m/d)	Specific yield	Specific storage (m^{-1})	Kzz/Kxy
28	Strzelecki 4km-6km	2×10^{-4}	1×10^{-5}	0.02	1×10^{-5}	0.050
29	Strzelecki >6km	2×10^{-4}	1×10^{-5}	0.02	1×10^{-5}	0.050
30	Palaeozoic basement 200m thick	1.012×10^{-1}	1.518×10^{-2}	0.02	1×10^{-5}	0.150
31	Lower M2 interseam	8.747	1.312	0.1	1×10^{-5}	0.150
32	Lower M2 interseam	6.077	6.273×10^{-1}	0.1	1×10^{-5}	0.103
33	Upper Latrobe Group	2.665	3.997×10^{-1}	0.1	1×10^{-5}	0.150
34	Upper Latrobe Group	2.930	3.163×10^{-1}	0.12	1×10^{-5}	0.108
35	Palaeozoic basement 200m thick	1.950	2.337×10^{-2}	0.04	1×10^{-5}	0.012
36	Quaternary	1.501×10^{-1}	2.009×10^{-2}	0.07	1×10^{-5}	0.134

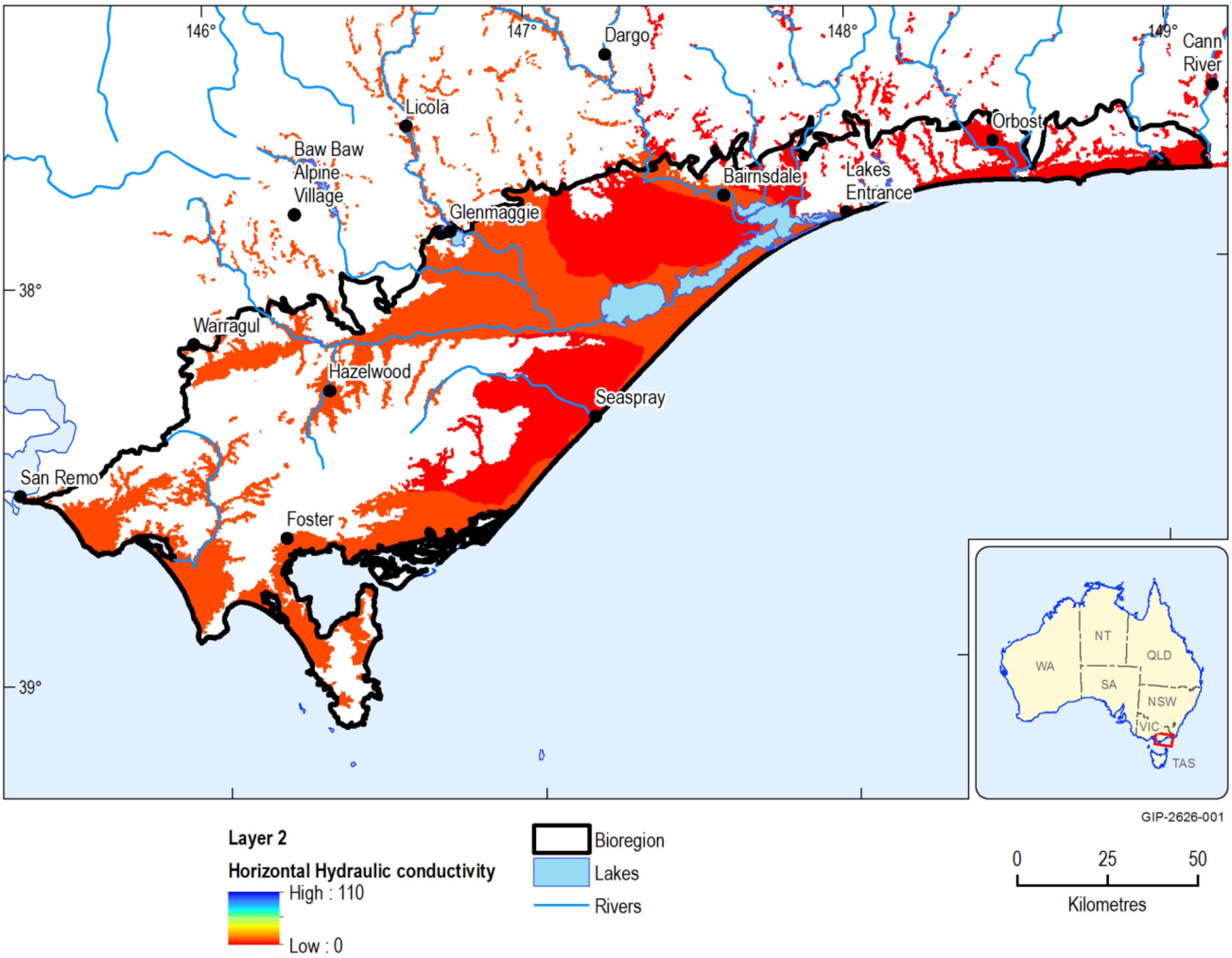


Figure 130 Lateral hydraulic conductivity (m/day) for modelled layer 2

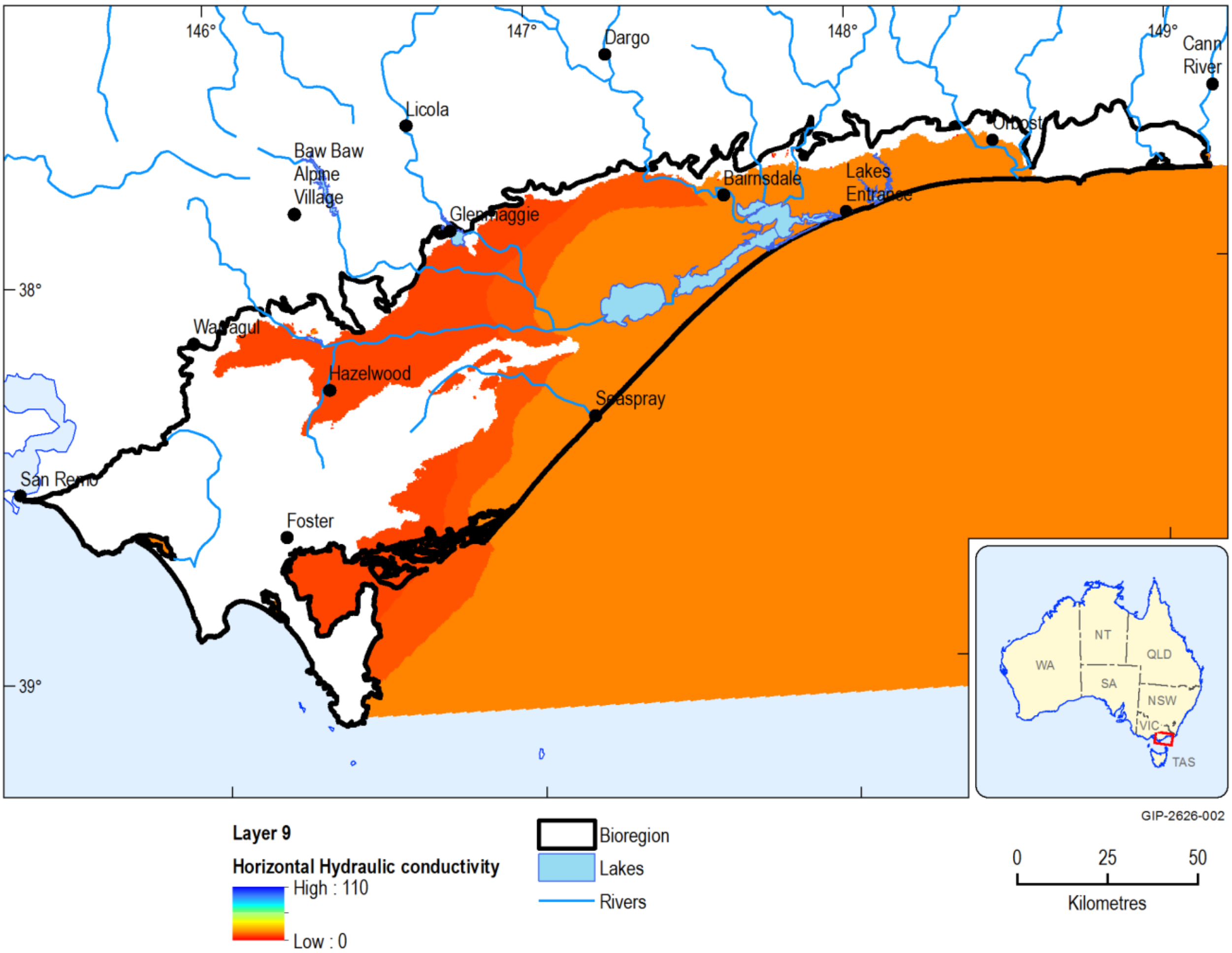


Figure 131 Lateral hydraulic conductivity (m/day) for modelled layer 9

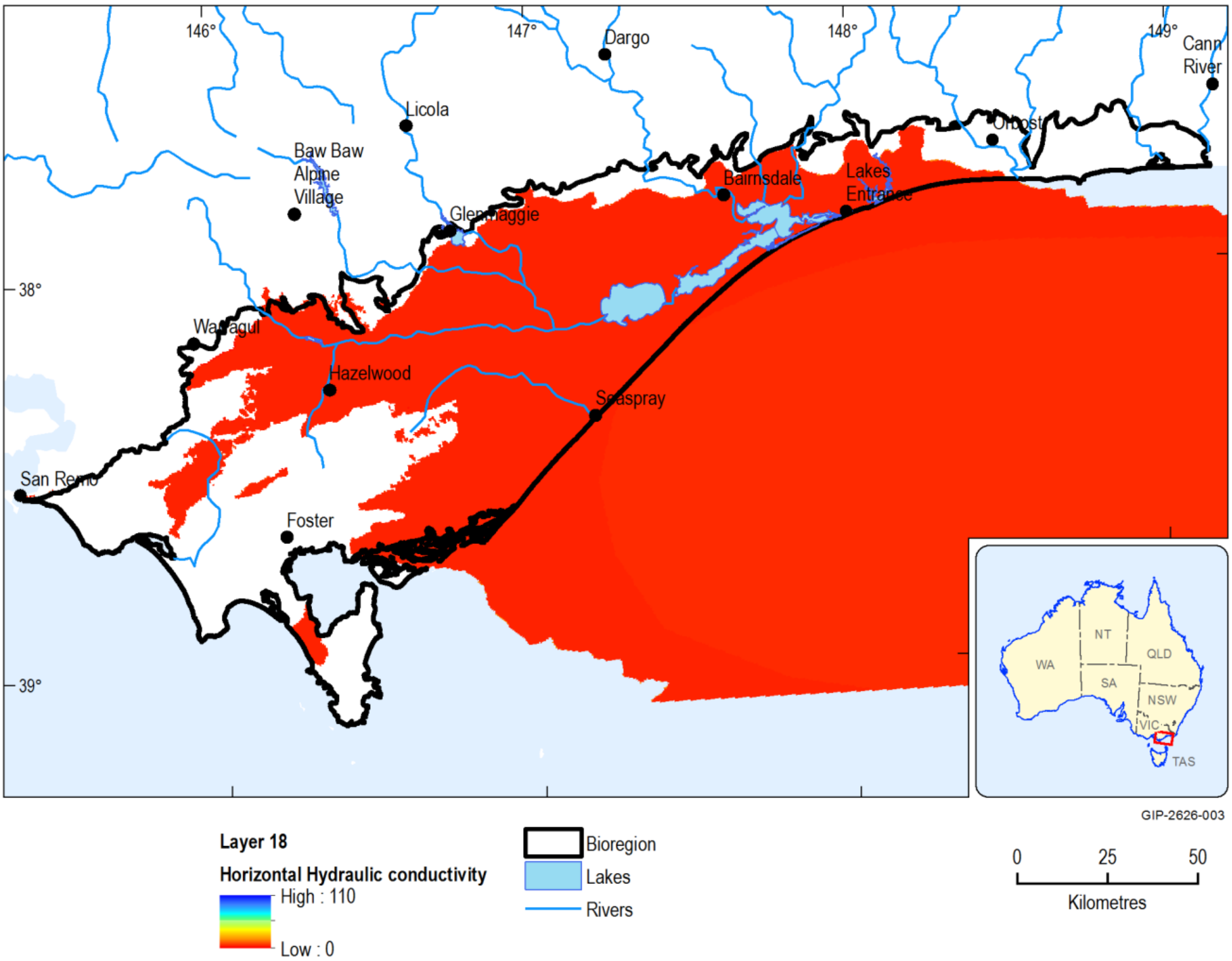


Figure 132 Lateral hydraulic conductivity (m/day) for modelled layer 18

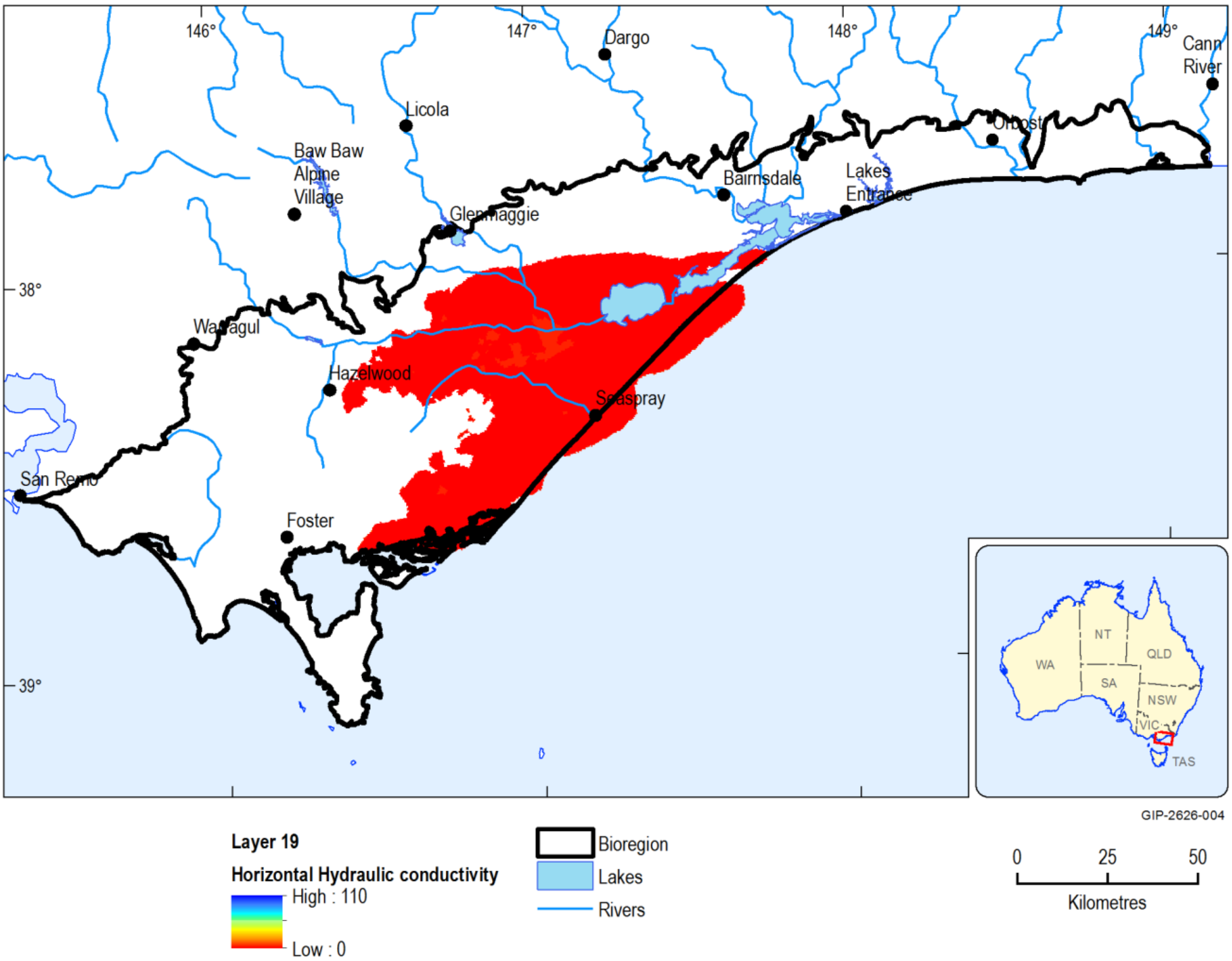


Figure 133 Lateral hydraulic conductivity for modelled layer 19

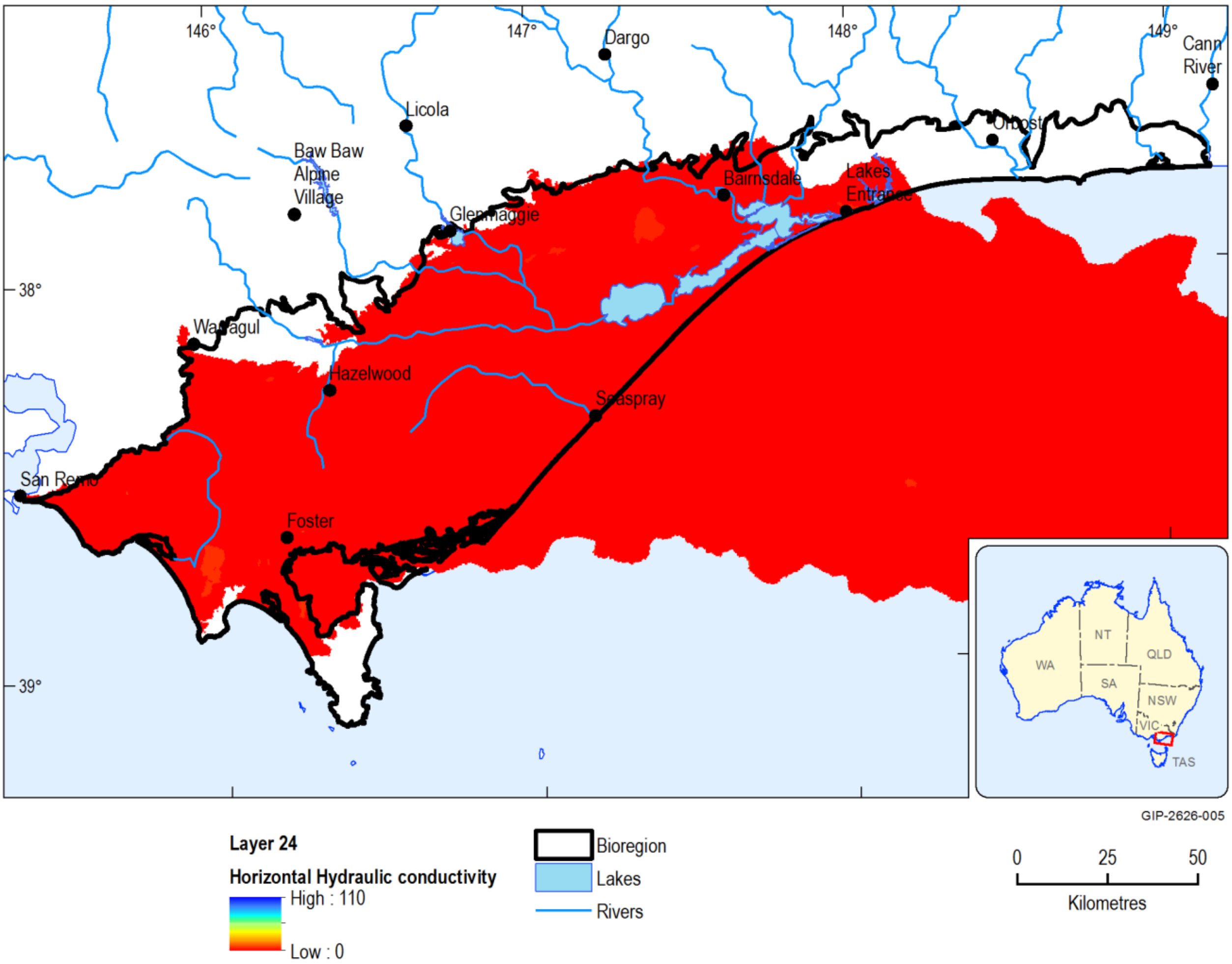


Figure 134 Lateral hydraulic conductivity (m/day) for modelled layer 24

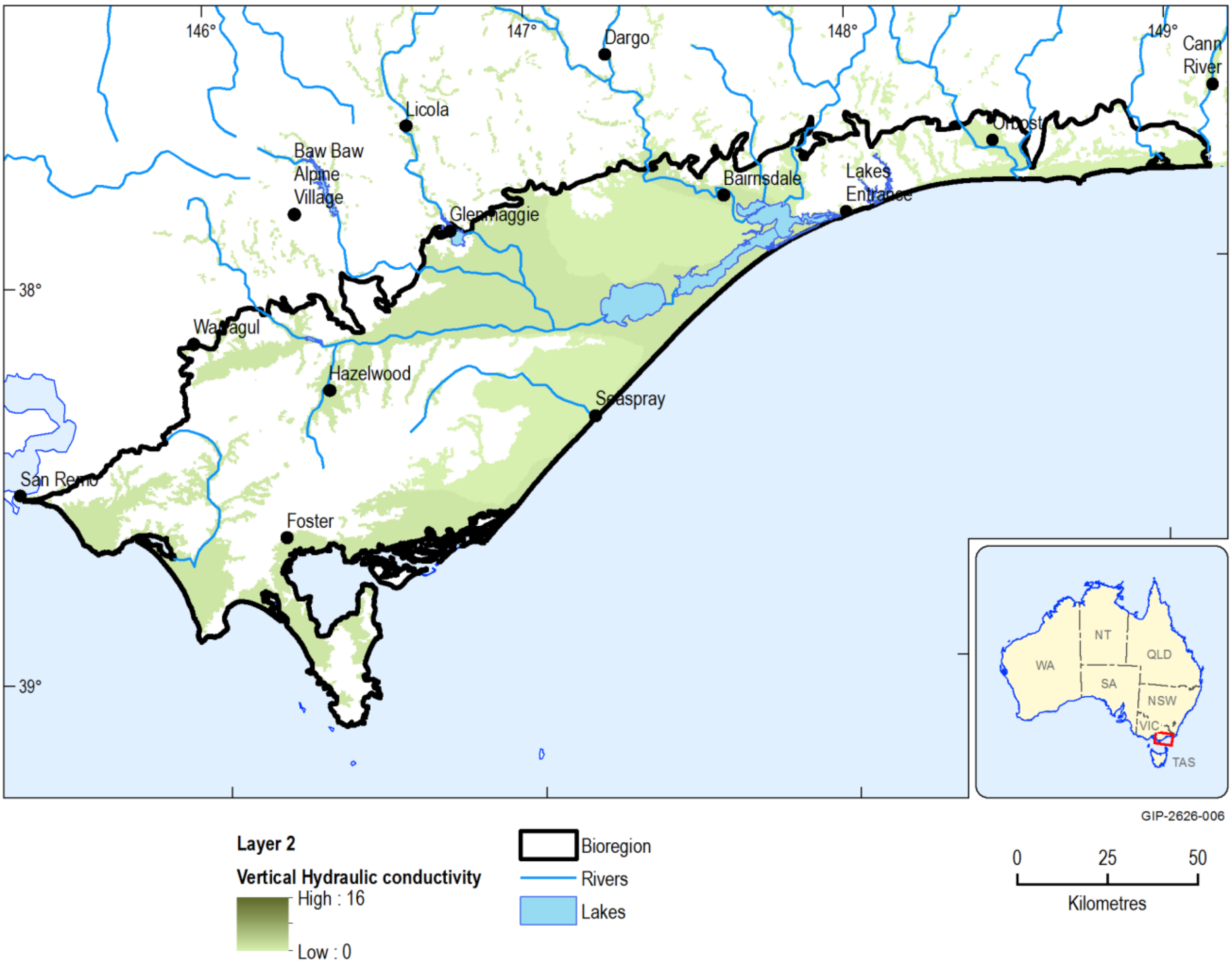


Figure 135 Vertical hydraulic conductivity (m/day) for modelled layer 2

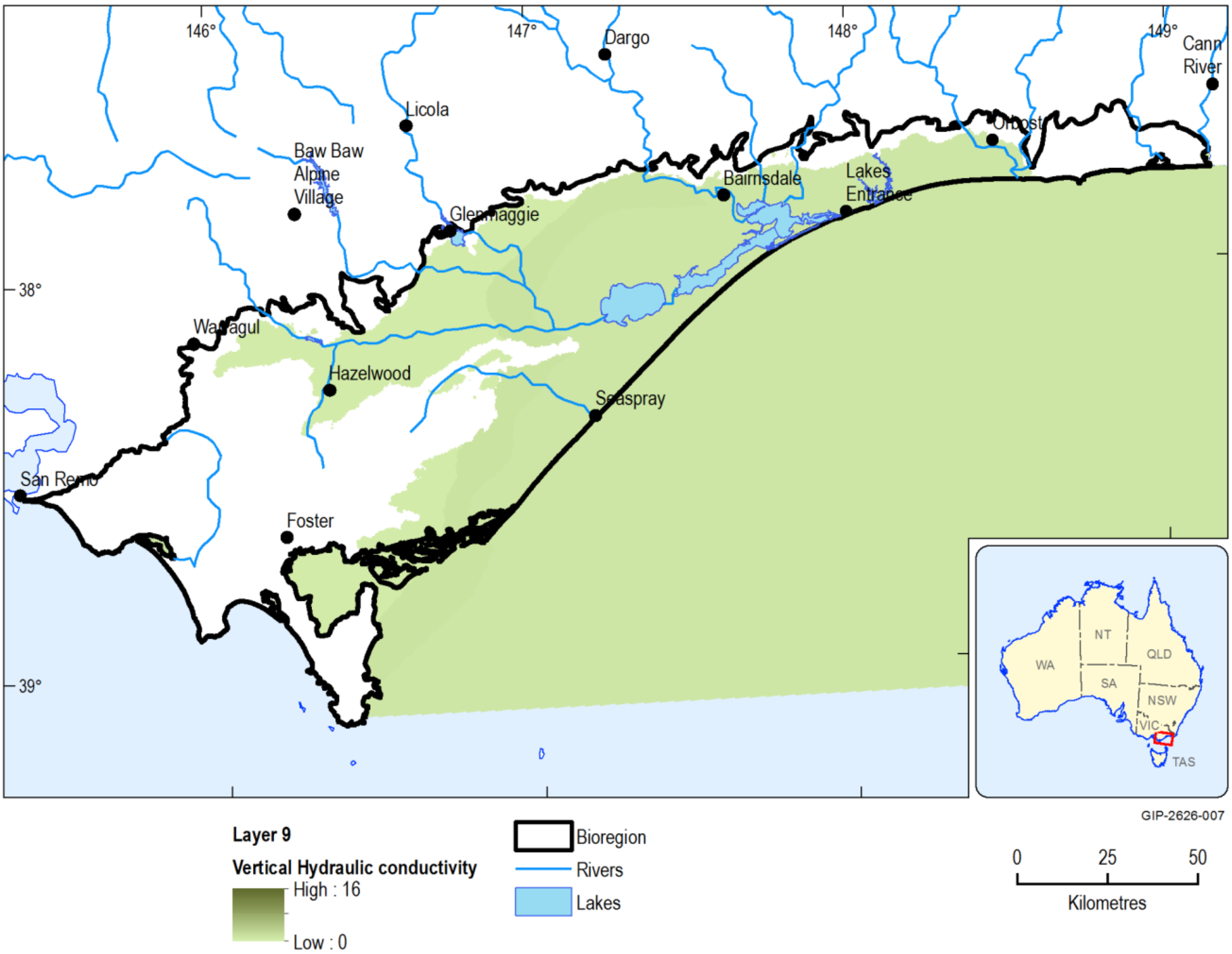


Figure 136 Vertical hydraulic conductivity (m/day) for modelled layer 9

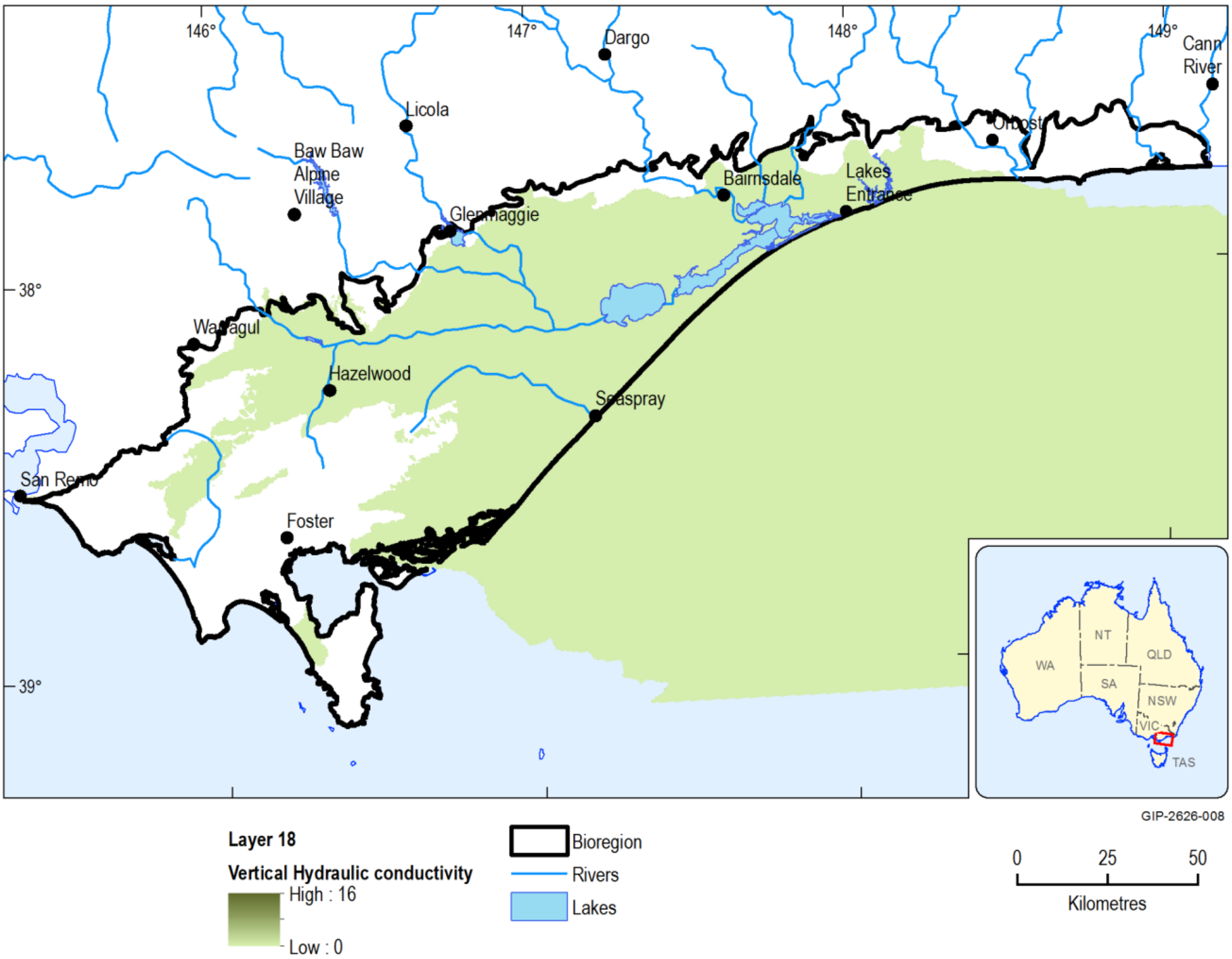


Figure 137 Vertical hydraulic conductivity (m/day) for modelled layer 18

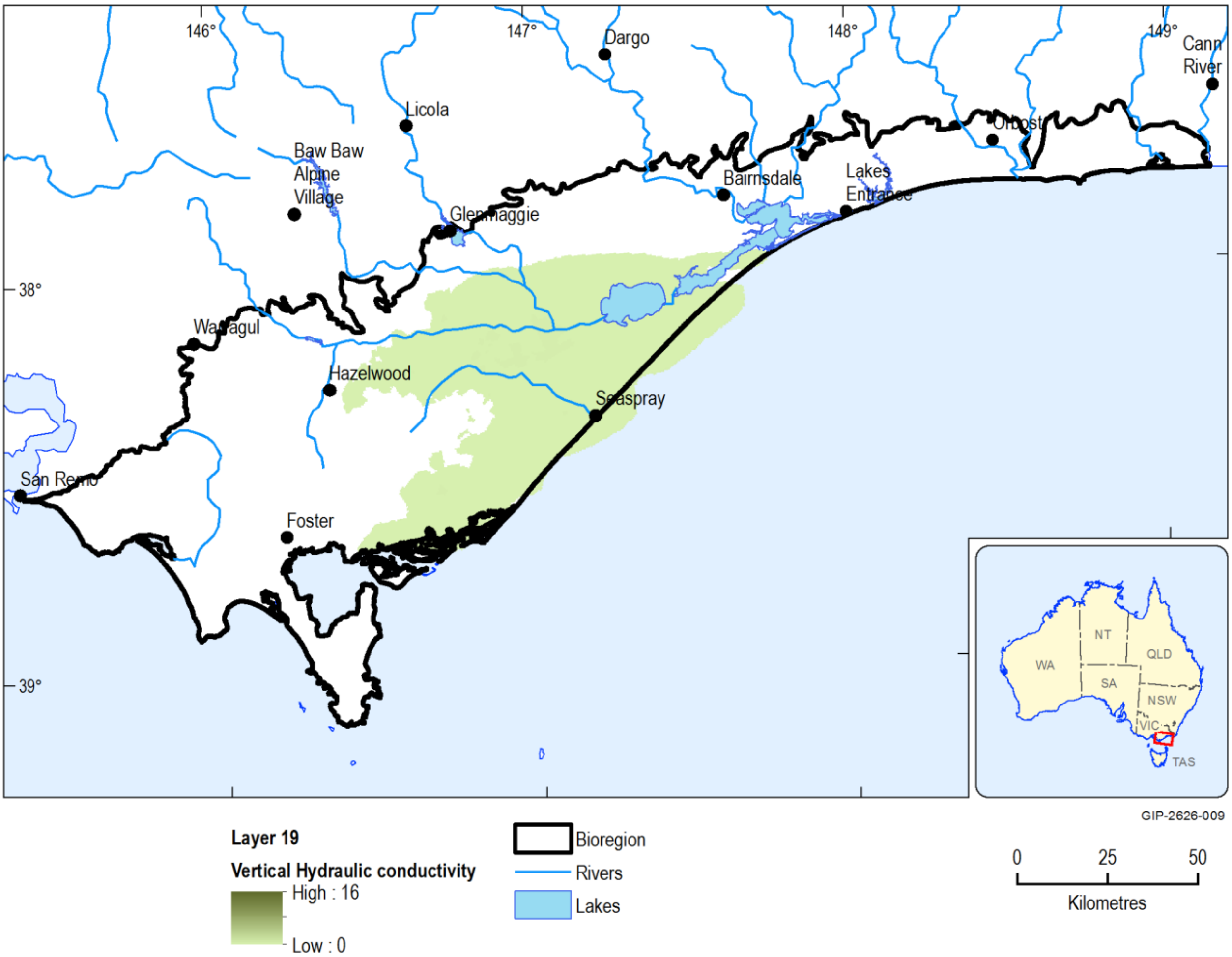


Figure 138 Vertical hydraulic conductivity (m/day) for modelled layer 19

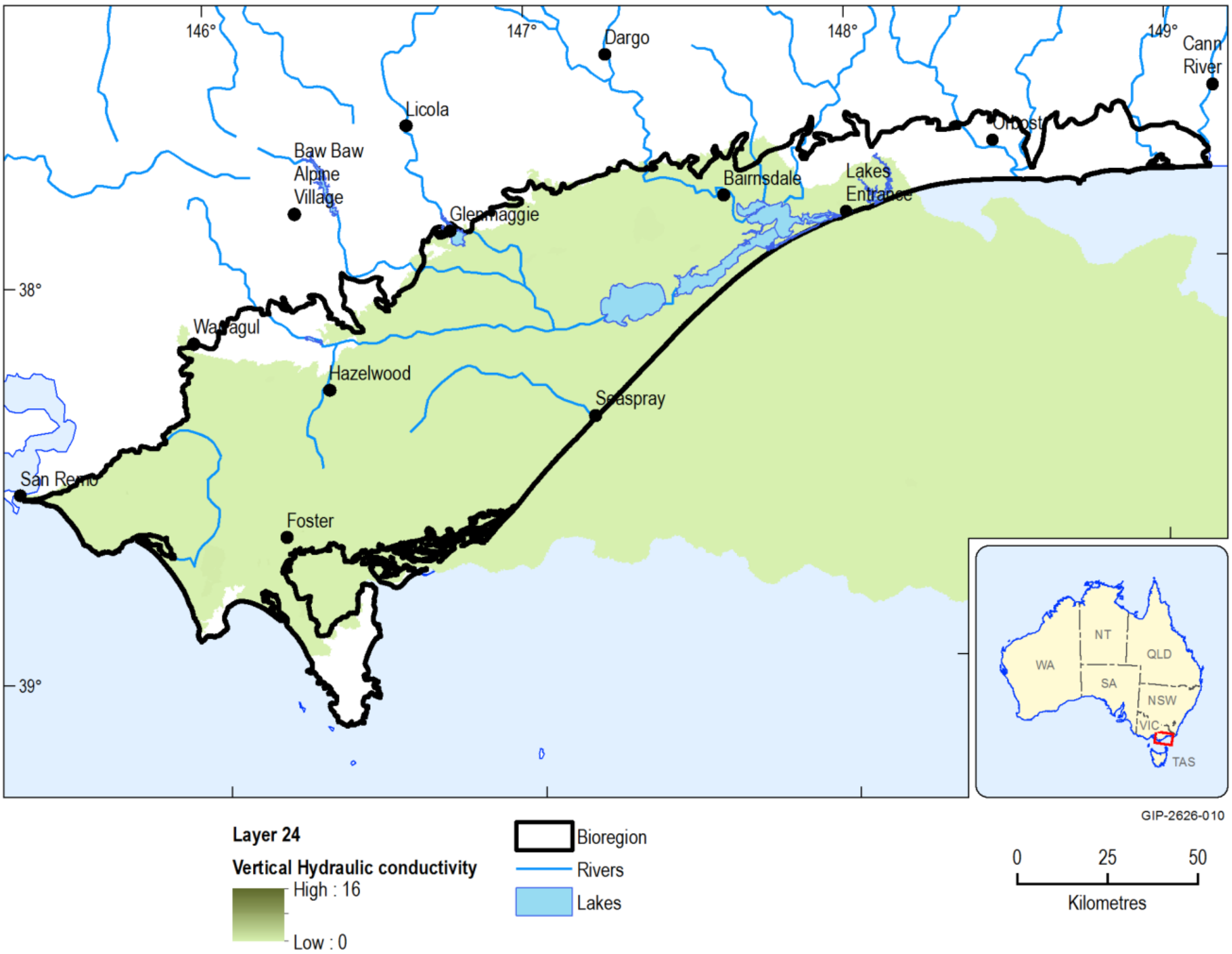


Figure 139 Vertical hydraulic conductivity (m/day) for modelled layer 24

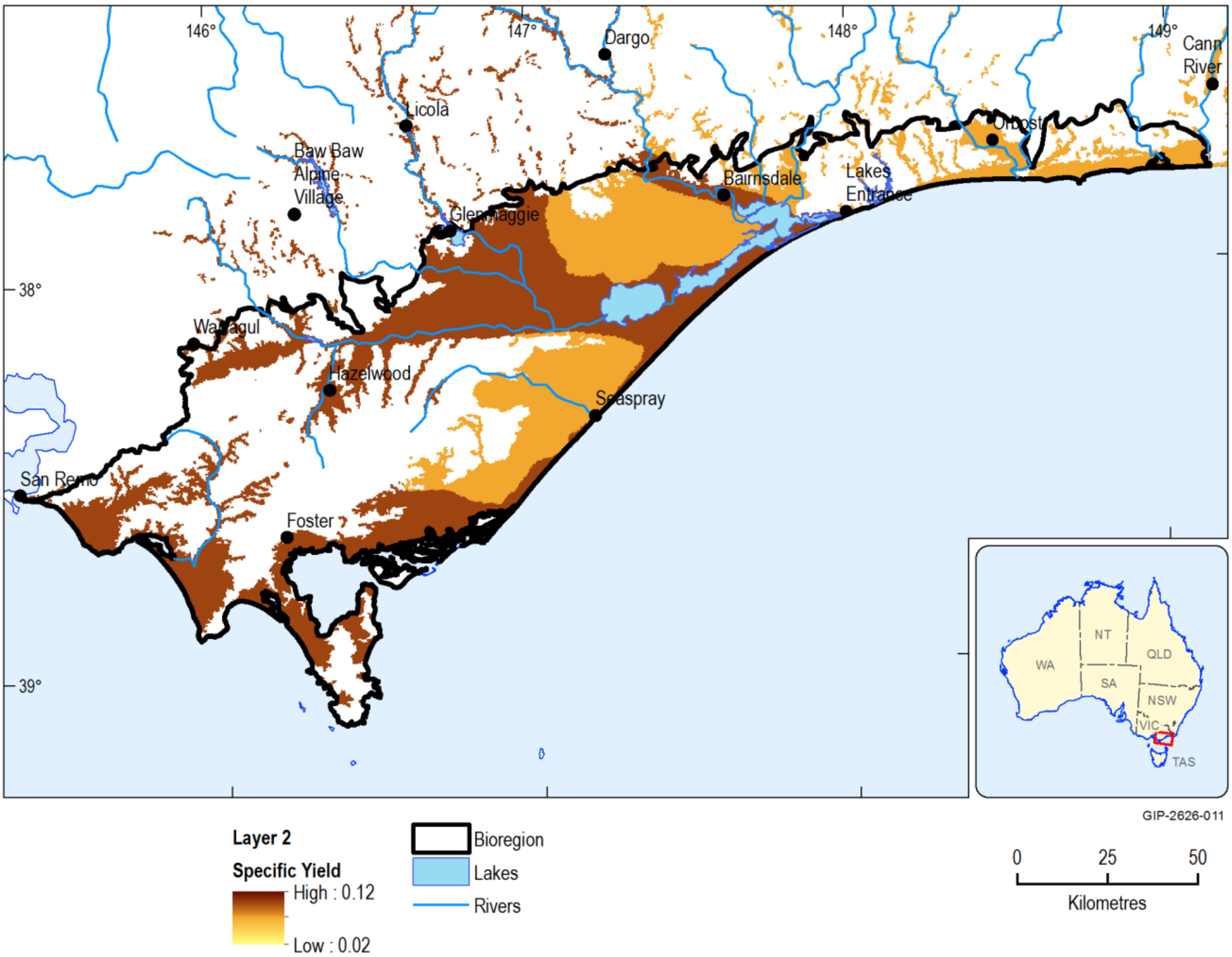


Figure 140 Specific yield for modelled layer 2

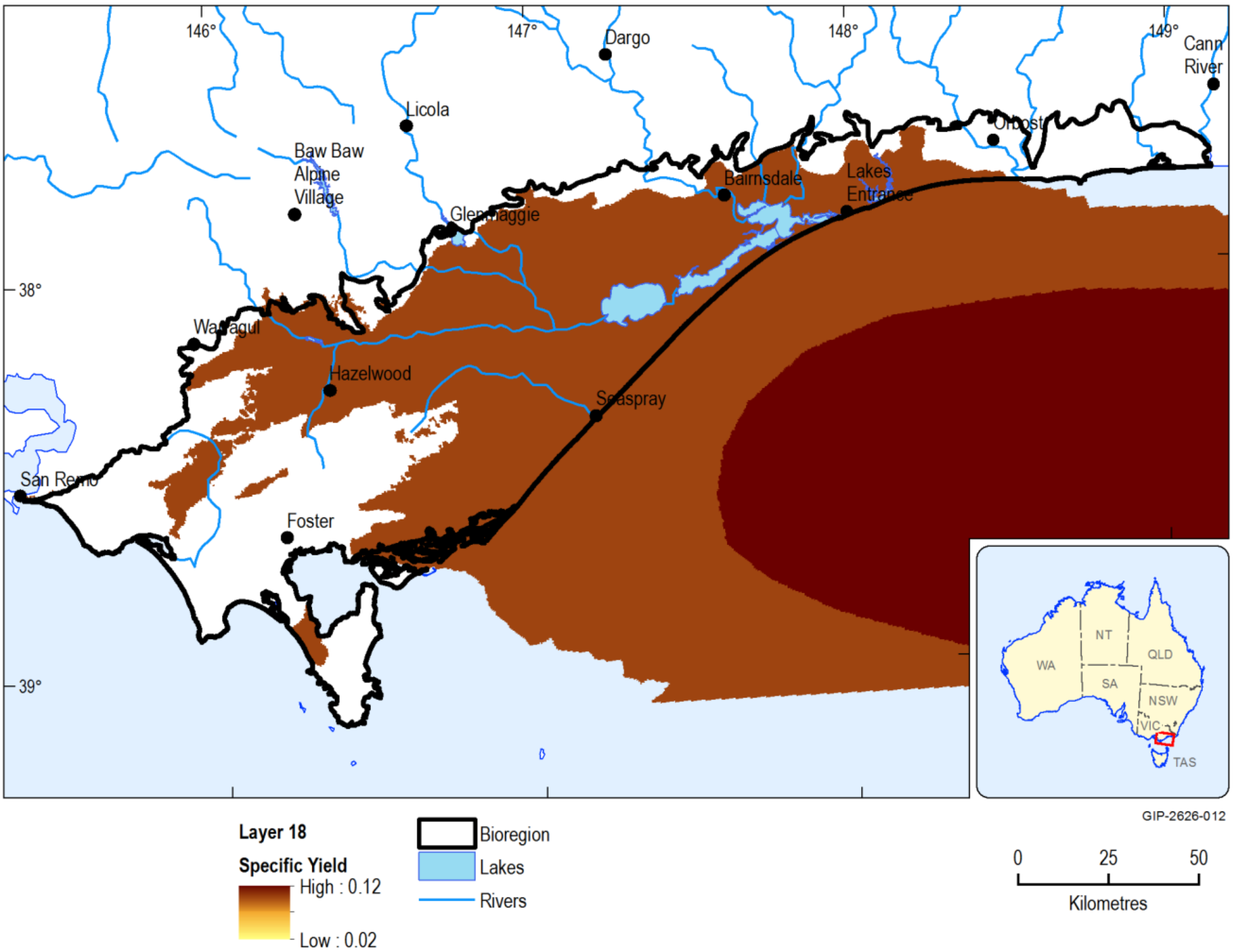


Figure 141 Specific yield for modelled layer 18

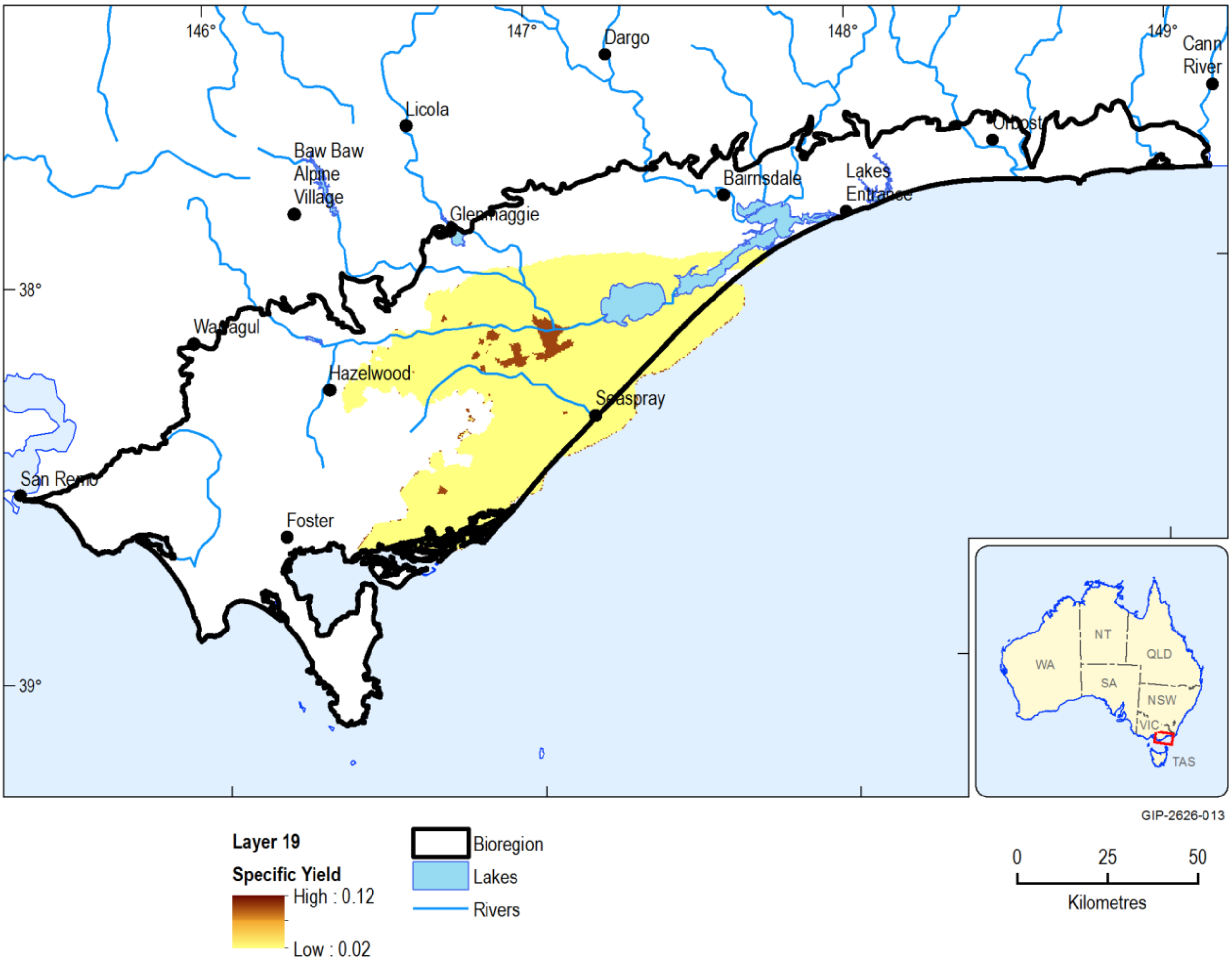


Figure 142 Specific yield for modelled layer 19

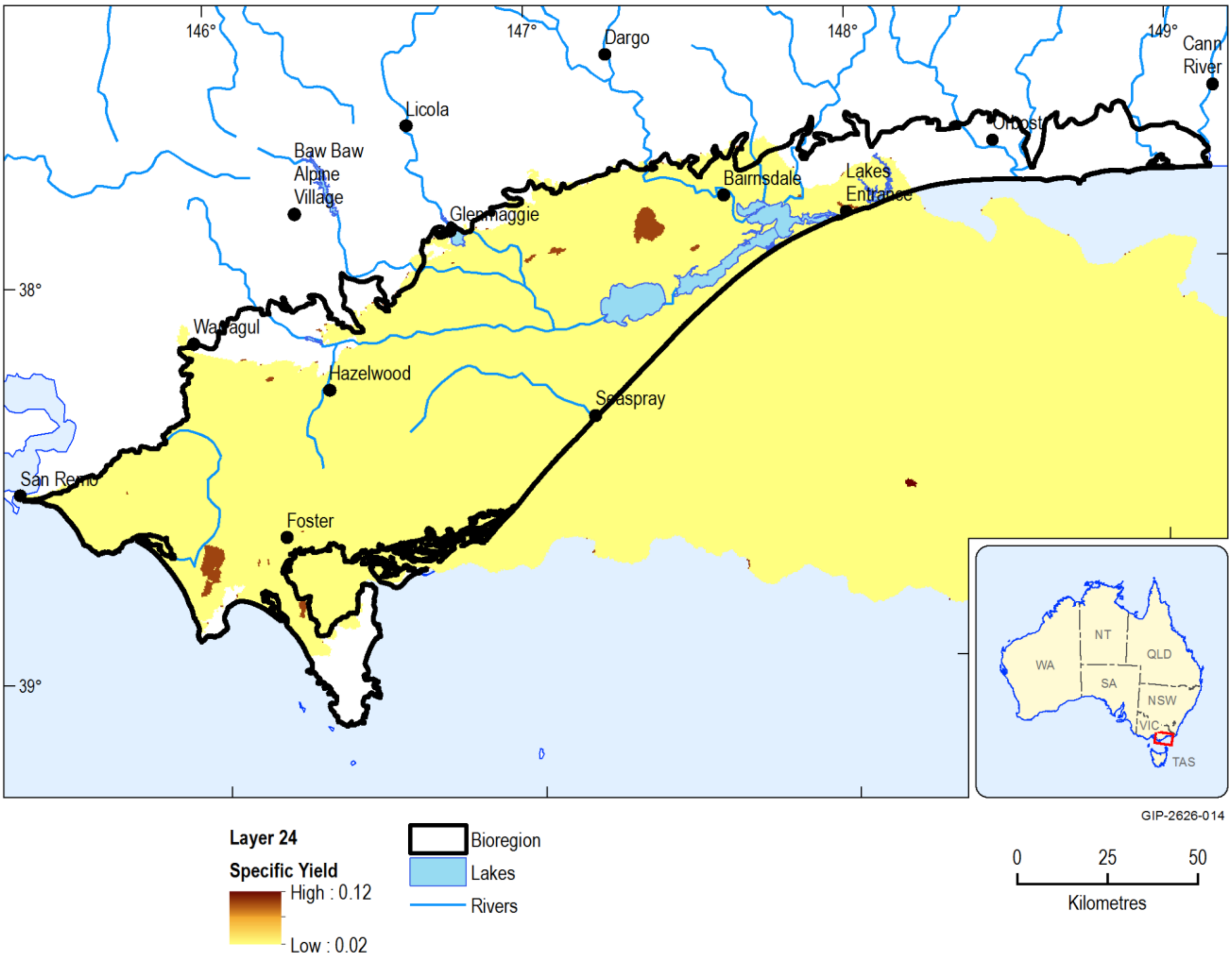


Figure 143 Specific yield for modelled layer 24

2.6.2.7 Observations and predictions

Summary

The calibration statistics for the transient groundwater model achieved the target scaled a normalised (scaled) root mean squared error (RMS) of less than 5%. Of note was that the 2000 to 2010 verification period displayed improved calibration statistics with a scaled RMS of 1.42%, a mean sum of residuals of 5 m and a coefficient of determination of 0.9. Analysis of the spatial residual error suggest that the model over predicts the heads in the outcropped regions and under predicts the heads in the lower parts of the landscape.

Results from the sensitivity analysis indicate high sensitivity of simulated shallow water table extent to variations in recharge and maximum groundwater evapotranspiration. This is not surprising and suggests that the groundwater model is well calibrated to key inputs. The sensitivity analysis shows model parameters fit within type I or II classification of the Murray-Darling Basin Groundwater Flow Modelling Guideline.

The difference between CRDP and baseline is known as the additional coal resource development (ACRD). The ACRD is the change that is primarily reported in the BA (see Section 2.3.1.1 of companion product 2.3 for the Gippsland Basin bioregion). An evaluation of the impact of the ACRD estimates that the greatest spatial impact of 167,700 ha is likely to occur around 2072. This is consistent with the timing of the peak reduction in annual baseflow of 78 ML/yr to the Latrobe River. Simulation results suggest that:

(i) the maximum impact of the CRDP is localised around the mine pits

(ii) drawdowns of greater than 2 m, 5 m and 10 m impact an area of 167,696 ha, 87,200 ha and 50, 976 ha respectively with maximum drawdowns of greater than 100 m impacting 1,328 ha in the vicinity of the mine pits

(iii) the greatest impact on baseflow to the Latrobe River occurs post mine closure.

2.6.2.7.1 Observation bore data

All available groundwater observation bore data was compiled and included in the model as calibration targets. A total of 822 target bores are utilised for the transient calibration model whereas only 71 bores have data available to calibrate the predevelopment steady-state condition. Figure 144 shows the location of the observation bores used for model calibration. Bore hydrographs identified in SKM (2014) and GHD (2014a) are considered “high reliability” and were assigned a calibration weight of 5; all other observation bore data were assigned a calibration weight of 1.

Summarised in Table 24 are all the bores used to calibrate the groundwater model. Included in the table are the layer allocations based on the VAF data (VAF Lay) and the corresponding layer allocation based on bore depth and surface elevation data (New Lay). The top and bottom elevations of the VAF assigned layer (columns TopLay and BotLay respectively) are included for comparison with the associated bore depth. The tabled information suggests that in most cases the VAF assigned bore layer varies from the depth based layer as reported by the last column of Table 24.

Table 24 Calibration bore attribution

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
114161	3	2568202	2315100	6	9. 56	3. 56	1.66	-0.34	2	yes
114156	3	2568974	2314144	38	0	-38	-5.73	-7.73	19	yes
114157	3	2568974	2314142	17	0	-17	-5.73	-7.73	8	yes
114158	3	2568974	2314141	11	0	-11	-5.73	-7.73	5	yes
94807	2	2568974	2314146	4	0	-4	-3.73	-5.73	2	no
94814	3	2569007	2313783	9	12	3	3.16	1.01	3	no
94813	3	2570892	2310487	21	12.15	-8.85	9.7	6.99	9	yes
94804	2	2571195	2311454	4	7.48	3.48	7.11	3.41	2	no
94816	3	2571454	2310076	12	5.97	-6.03	8.43	6.27	9	yes
94815	2	2571634	2310081	1	5.97	4.97	16.82	8.43	4	yes
94803	3	2572449	2311040	6	3	-3	-0.63	-2.63	4	yes
94802	2	2572605	2310763	4	6.99	2.99	4.9	0.85	2	no
113124	3	2572605	2310763	22	6.99	-15.01	0.85	-1.15	10	yes
113125	3	2572606	2310763	12	6.99	-5.01	0.85	-1.15	5	yes
75405	17	2572685	2329154	16	74.84	58.84	48	40.09	11	yes
75404	18	2574268	2332762	70	68.94	-1.06	29.8	20.57	21	yes
61429	18	2574390	2323889	28	66	38	40.62	33.35	18	no
75566	18	2574974	2330073	29	59	30	23.75	20.93	14	yes
61430	18	2576510	2323093	25	86	61	41.25	38.08	8	yes
75399	17	2576679	2325405	16	55	39	30.79	12.22	12	yes
75400	17	2576892	2327769	20	38	18	5.79	-5.95	10	yes
75401	18	2578498	2330054	26	32.87	6.87	-0.9	-4.75	14	yes
61184	30	2578770	2375435	38	174	136	58.57	-141.43	23	yes
75565	18	2580601	2336533	68	94	26	94.26	78.82	22	yes
75403	18	2581386	2330524	84	38	-46	-6.19	-14.54	22	yes
75563	18	2582856	2337821	29	73	44	59.78	48.99	19	yes
71148	18	2585325	2337641	79	46	-33	-14.24	-19.08	21	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
71149	18	2585360	2337644	65	46	-19	-14.24	-19.08	18	no
100979	2	2596905	2296875	3	8.17	5.17	3.95	-0.02	0	yes
100978	2	2597197	2297400	1	4.94	3.94	-2.9	-4.9	0	yes
100980	2	2597499	2296386	4	11.24	7.24	2.14	-0.03	0	yes
100977	2	2598224	2296343	3	8.67	5.67	16.94	-0.06	2	no
100975	2	2598284	2295929	3	11.09	8.09	12.05	-0.04	2	no
100976	2	2598608	2296044	3	6.31	3.31	9.39	-0.09	2	no
79775	18	2600542	2364722	141	75	-66	-32.4	-45.44	20	yes
79774	30	2600569	2364712	0	75	n/a	-189.08	-389.08	30	no
110729	30	2601696	2376617	68	105	37	29.05	-170.95	26	yes
YG55	17	2602034	2367878	187	59.99	-127.01	-110.96	-156.59	17	no
79784	18	2603345	2356315	21	252.83	231.83	249.6	229.92	18	no
YG49	17	2604822	2368537	221	56	-165	-148.32	-164.89	18	yes
YG43	17	2605523	2370851	168	63	-105	-90.02	-131.46	17	no
YG34	10	2608727	2371814	58	68.1	10.1	32.18	27.29	14	yes
107971	17	2609634	2371458	111	78.97	-32.03	20.67	-58.85	17	no
107970	17	2609634	2371458	66	78.97	12.97	20.67	-58.85	17	no
107972	18	2609981	2369233	226	65	-161	-139.37	-141.37	28	yes
107973	17	2609981	2369233	136	65	-71	-52.9	-139.37	17	no
N3788	17	2611466	2370191	98	58	-40	-10.2	-59.61	17	no
84155	18	2612123	2364811	156	133.83	-22.17	-5.59	-7.59	26	yes
N3789	23	2612432	2369327	216	75.39	-140.61	-73.07	-75.07	30	yes
N3787	12	2613479	2368347	222	86	-136	-40.22	-54.95	30	yes
110731	18	2613789	2357471	69	90.11	21.11	39.36	10.53	18	no
N3726	23	2614021	2367934	197	103.98	-93.02	-52.08	-54.08	30	yes
84156	18	2614468	2365921	209	163.05	-45.95	-50.33	-52.33	17	yes
N3607	17	2614508	2361004	97	131.69	34.69	56.98	54.98	19	yes
N3615	14	2614602	2359409	69	89.21	20.21	57.85	55.85	18	yes
N3799	23	2614973	2366950	236	140.35	-95.65	-39.56	-41.56	30	yes
N3567	17	2615132	2361777	135	139.88	4.88	40.84	38.84	21	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
Y135	10	2615627	2350900	330	79.89	-250.11	-106.88	-108.88	19	yes
N3270	13	2615782	2358819	49	66	17	39.35	25.36	17	yes
N3288	10	2615836	2357563	49	75	26	48.16	46.16	14	yes
N3694	14	2615904	2357479	75	75	0	32.37	24.17	18	yes
N5952	14	2616110	2360737	144	87	-57	-14.87	-19.87	18	yes
N4558	14	2616386	2362578	178	88.73	-89.27	-64.61	-81.05	15	yes
N3263	14	2616411	2359248	102	67.94	-34.06	11.07	4.84	18	yes
N4651	9	2616643	2362376	194	79	-115	30.23	28.23	15	yes
N3780	17	2616695	2361984	200	81	-119	-114.94	-130.54	17	no
N3369	10	2616696	2361995	145	81	-64	33.37	28.84	14	yes
N4652	9	2616749	2363272	219	80.36	-138.64	31.76	29.76	16	yes
N3570	23	2616929	2358071	283	62	-221	-211.1	-482.18	23	no
N3271	14	2617255	2359681	120	59	-61	-45.73	-65.57	14	no
N2491	14	2617641	2358877	117	52	-65	-22.33	-41.69	16	yes
Y122	17	2617726	2351085	410	74	-336	-278.86	-283.34	20	yes
N4541	9	2618455	2361561	228	49	-179	-11.47	-13.47	16	yes
H1095	14	2618694	2357662	106	72	-34	21.44	12.17	17	yes
H1502	10	2618826	2354188	347	73	-274	-102.74	-148.07	18	yes
M3787	3	2619925	2364195	10	44.93	34.93	35.04	31.35	3	no
Y152	23	2620417	2350817	645	96.97	-548.03	-533.59	-705.45	23	no
M2758	14	2620950	2363802	276	69	-207	-184.49	-211.95	14	no
H1320	23	2621603	2355955	571	82	-489	-474.01	-974.01	23	no
H1691	18	2622148	2352910	429	105	-324	-202.01	-259.54	20	yes
M3282	9	2623325	2364252	250	72	-178	-30.31	-32.31	14	yes
TE1694	17	2623554	2369626	355	33.99	-321.01	-249.75	-259.32	30	yes
H1726	22	2623761	2351447	365	154.81	-210.19	-181.26	-219.72	22	no
H1719	20	2624946	2354097	352	112	-240	-183.63	-239.99	21	yes
H1348	12	2625037	2356496	643	109	-534	-130.55	-216.32	23	yes
H1632	17	2625505	2358509	703	88.1	-614.9	-519.68	-521.68	22	yes
H1631	12	2625507	2358524	298	88.1	-209.9	-197.54	-269.22	12	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
H1333	16	2625515	2358500	600	88.1	-511.9	-509.26	-519.68	16	no
M3101	17	2625832	2362004	694	62	-632	-489.94	-496.25	23	yes
M3054	14	2626343	2368322	357	57.25	-299.75	-266.75	-307.76	14	no
M942	7	2626659	2367886	529	43	-486	-27.79	-124.35	20	yes
T487	9	2627182	2355413	303	116.99	-186.01	1.97	-1.73	15	yes
M3190	14	2627377	2365373	463	47.41	-415.59	-341.02	-456.66	14	no
110724	9	2627413	2313451	119	9	-110	-43.98	-55.23	14	yes
T426	12	2628599	2357891	202	106.98	-95.02	-85.74	-126.72	12	no
BB195	23	2629104	2370602	480	43	-437	-359.07	-460.48	23	no
T493	10	2629164	2363251	267	60.3	-206.7	-210.32	-246.92	8	yes
T494	23	2629164	2363251	712	60.3	-651.7	-618.72	-1118.7	23	no
T454	23	2630325	2359681	644	100.97	-543.03	-544.64	-1044.6	22	yes
T440	14	2630346	2359679	294	100.97	-193.03	-174.39	-293.37	14	no
BB196	9	2630715	2369875	360	35.98	-324.02	-71.88	-90.01	15	yes
T256	23	2631780	2357668	536	159.39	-376.61	-358.35	-858.35	23	no
T485	23	2632831	2367857	704	44	-660	-598.85	-1098.8	23	no
TS37	23	2632959	2370884	607	34	-573	-557.39	-856.45	23	no
T489	23	2633154	2360587	627	120.34	-506.66	-439.08	-939.08	23	no
T445	18	2633252	2363852	632	87	-545	-451.29	-473.66	22	yes
T466	23	2633307	2364240	722	77.06	-644.94	-574.96	-1075	23	no
T442	23	2633472	2354615	149	143.63	-5.37	-32.83	-532.83	21	yes
T495	23	2633534	2355971	242	122.24	-119.76	-146.93	-646.93	22	yes
T496	19	2633534	2355973	182	122.24	-59.76	47.83	25.14	21	yes
LY3298	23	2634759	2355782	243	84	-159	-108.99	-608.99	23	no
LY3299	20	2634760	2355786	115	84	-31	34.89	-13.07	21	yes
LY3055	20	2634887	2362019	420	55	-365	-323.31	-366.79	20	no
T433	12	2634984	2366881	353	39.76	-313.24	-287.33	-308.72	13	yes
T491	20	2635423	2362597	529	62.98	-466.02	-385.32	-419.78	22	yes
LY2477	23	2635544	2357010	226	82.31	-143.69	-150.18	-650.18	22	yes
TS40	11	2636291	2371312	330	31.6	-298.39	-168.16	-305.8	11	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
110721	9	2637094	2324642	25	26	1	11.19	-13.5	9	no
LY3118	23	2637659	2364370	607	90	-517	-510.39	-1010.4	23	no
LY3119	10	2637670	2364367	150	90	-60	-79.2	-129.89	8	yes
TS38	20	2637732	2372083	575	30	-545	-507.3	-527.89	21	yes
TS32	17	2639294	2375777	430	54	-376	-302.87	-338.98	23	yes
LY2268	14	2639531	2367013	451	51	-400	-352.69	-442.46	14	no
LY2676	20	2639563	2367251	705	51	-654	-571.26	-606.51	22	yes
TS42	23	2640827	2372258	621	31	-590	-578.57	-1078.6	23	no
LY2472	23	2642202	2363504	570	60	-510	-500.11	-1000.1	23	no
76074	30	2643006	2367953	0	31	n/a	-2530.2	-2730.2	30	no
110722	9	2643027	2367954	0	31	n/a	-177.81	-185.53	9	no
TB212	23	2643128	2354433	193	186.11	-6.89	35.64	-464.36	23	no
TN25	30	2643402	2381160	433	70.83	-362.17	-477.9	-677.9	23	yes
TS34	30	2643796	2378073	514	52	-462	-1051.7	-1251.7	23	yes
TB214	12	2644238	2359737	117	91.87	-25.13	63.6	-22.36	13	yes
76079	18	2644285	2368211	703	33.71	-669.29	-569.95	-571.95	21	yes
TB213	12	2644367	2360412	147	88	-59	56.17	-38.24	14	yes
TB220	12	2644636	2358912	256	110.4	-145.6	7.73	-89.14	19	yes
LY2678	23	2644987	2366319	691	63	-628	-639.33	-1139.3	22	yes
LY2310	14	2644989	2366328	347	63	-284	-264.49	-339.06	14	no
TB205	19	2645186	2357946	189	153.35	-35.65	56.21	-37.66	19	no
TB198	20	2645269	2358285	199	167.84	-31.16	-22.09	-76.9	20	no
TB176	20	2645685	2359864	528	119.92	-408.08	-308.82	-348.52	22	yes
TB165	9	2645751	2359904	271	119.92	-151.08	78.42	76.42	15	yes
TB167	22	2645828	2354613	196	217.38	21.38	55.43	-88.28	22	no
LY1967	23	2646204	2364366	656	77	-579	-619.58	-1119.6	22	yes
LY1979	14	2646328	2364358	400	77	-323	-310.14	-373.82	14	no
LY2883	3	2646335	2364355	71	77	6	50.74	31.28	5	yes
LY2809	9	2646402	2364342	456	77	-379	-122.91	-124.91	15	yes
LY2810	20	2646418	2364339	658	77	-581	-472.35	-521.43	22	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
105220	18	2646432	2327644	329	27.7	-301.3	-223.96	-225.96	21	yes
TS36	23	2647000	2372700	743	29	-714	-717.22	-1217.2	22	yes
LY2269	14	2647013	2368728	403	44.36	-358.64	-331.64	-408.88	14	no
TN24	30	2647139	2386406	358	62	-296	-214.75	-414.75	30	no
R330	23	2647174	2361701	665	85.25	-579.75	-563.82	-1063.8	23	no
TS43	20	2648186	2375355	644	27.98	-616.02	-550.06	-570.42	23	yes
105222	18	2648660	2325903	318	24	-294	-173.26	-230.01	20	yes
105221	18	2649379	2327361	185	40.77	-144.23	-43.06	-45.06	21	yes
45759	3	2650353	2378495	20	41	21	29.06	21.69	4	yes
45760	3	2650353	2378495	12	41	29	29.06	21.69	3	no
103811	8	2650359	2378494	78	41	-37	-103.25	-134.25	6	yes
147173	18	2650869	2325257	238	16	-222	-217.72	-219.72	19	yes
R324	9	2651453	2369213	400	35	-365	-119.14	-139.12	14	yes
R340	9	2651482	2369201	558	35	-523	-119.14	-139.12	15	yes
R344	3	2651644	2362903	451	71.78	-379.22	84.51	69.33	23	yes
147174	9	2652295	2317015	156	4.72	-151.28	-216.4	-218.4	7	yes
110726	18	2652400	2324979	520	19	-501	-259.87	-261.87	21	yes
45757	3	2653706	2377948	13	29	16	21.81	13.81	3	no
45756	3	2653706	2377948	28	29	1	21.81	13.81	5	yes
WN47	9	2654438	2372380	452	60	-392	-174.54	-196.14	13	yes
WL196	23	2654621	2358697	402	135.54	-266.46	-216.36	-716.36	23	no
WL197	21	2654640	2358703	358	135.54	-222.46	-133.56	-147.24	23	yes
45758	2	2655668	2374732	6	23	17	34.07	11.35	2	no
R343	22	2656046	2364512	358	87.86	-270.14	-200.25	-305.38	22	no
103822	4	2657145	2377374	91	23	-68	-9.06	-129.65	4	no
103820	8	2658261	2384698	64	37	-27	-27.73	-43.22	7	yes
45764	3	2658276	2375990	20	21	1	12.46	-45.73	3	no
45765	3	2658276	2375990	12	21	9	12.46	-45.73	3	no
WN52	20	2658441	2379797	703	28	-675	-577.22	-608.74	23	yes
DN58	9	2659538	2372849	572	31	-541	-158.8	-219.8	15	yes

2.6.2.7.1 Observation bore data

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
45761	3	2660163	2375868	24	23	-1	11.04	-15.53	3	no
45762	3	2660163	2375868	11	23	12	11.04	-15.53	2	yes
45763	2	2660163	2375868	4	23	19	34.82	11.04	2	no
R323	11	2660757	2366250	219	109.16	-109.84	54.83	4.51	14	yes
89809	18	2661060	2370220	804	15	-789	-708.65	-710.65	22	yes
R325	12	2661080	2370219	373	15	-358	-324.71	-357.05	13	yes
145094	5	2661499	2332102	0	57.12	n/a	6.56	-17.14	5	no
DN56	9	2662121	2373826	434	42	-392	-133.49	-135.49	14	yes
58937	18	2662747	2379792	710	23.89	-686.11	-674.39	-676.39	19	yes
HP207	21	2663024	2361507	359	165.04	-193.96	-107.14	-121.52	23	yes
S51	23	2663451	2353016	362	196.51	-165.49	-165.84	-665.84	22	yes
HP221	19	2664291	2362982	327	161.24	-165.76	17.32	-7.26	23	yes
59308	4	2664623	2381390	65	23	-42	2.46	-89.14	4	no
HP196	23	2665014	2362962	339	154.74	-184.26	-143.19	-643.19	23	no
HP204	10	2665364	2369310	313	17.16	-295.84	-157.11	-167.82	14	yes
92118	18	2665789	2349930	214	154.47	-59.53	-28.7	-30.7	19	yes
DN341	22	2665917	2381168	692	25.5	-666.5	-675.35	-697.84	21	yes
58934	5	2666053	2374972	122	17	-105	-82.96	-109.81	5	no
145090	5	2666243	2324016	0	12	n/a	-52.3	-79.06	5	no
HP220	19	2667289	2368318	302	41.45	-260.55	-219.6	-245.22	20	yes
HP177	21	2667300	2365125	183	130.59	-52.41	-24.93	-47.56	22	yes
HP188	21	2667311	2365094	229	130.59	-98.41	-24.93	-47.56	23	yes
HP189	21	2667314	2365075	216	130.59	-85.41	-24.93	-47.56	23	yes
95482	5	2667529	2388040	67	26	-41	-30.89	-42.92	5	no
67442	30	2669134	2369326	120	19.06	-100.94	-3067.4	-3267.4	8	yes
105134	9	2669366	2376001	0	31.72	n/a	-143.23	-206.54	9	no
110725	18	2670480	2376025	668	32	-636	-556.96	-558.96	22	yes
67441	18	2671405	2368736	889	39.1	-849.9	-628.01	-639.27	22	yes
C97	21	2671536	2359557	254	118.72	-135.28	2.25	-41.48	22	yes
105132	3	2671954	2376198	28	31	3	21.05	-24.92	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
105196	5	2672137	2378998	123	18	-105	-91.06	-103.21	6	yes
C93	21	2672162	2363449	126	142.33	16.33	29.92	-4.53	21	no
105547	5	2673156	2374585	154	13	-141	-112.64	-128.83	6	yes
C96	21	2673608	2361845	222	152.61	-69.39	17.12	-17.52	22	yes
98028	9	2673618	2404058	55	52	-3	33.72	27.5	14	yes
C94	23	2673622	2361830	233	152.61	-80.39	-76.9	-576.9	23	no
104536	18	2673691	2328292	993	2	-991	-834.63	-836.63	21	yes
BDL11	2	2674741	2382600	0	12	n/a	9.97	7.97	2	no
52752	9	2675691	2390117	115	32	-83	-47.92	-102.93	9	no
51532	30	2676358	2405156	0	49	n/a	-39.38	-239.38	30	no
105548	5	2677006	2374317	145	24	-121	-104.08	-126.04	5	no
52754	18	2677284	2377910	879	8	-871	-760.31	-762.31	21	yes
52753	5	2677730	2379523	169	17	-152	-104.62	-115.14	9	yes
110172	2	2679710	2404836	3	53	50	39.31	37.31	0	yes
64835	18	2679945	2359719	233	78.46	-154.54	-66.05	-68.05	20	yes
110171	3	2679975	2404783	6	53	47	37.31	33.59	0	yes
92176	9	2680120	2396546	73	35.43	-37.57	-31.77	-57.61	9	no
92175	18	2681697	2401558	87	67.8	-19.2	-12.4	-35.13	18	no
145092	5	2682235	2344458	0	27	n/a	-56.05	-73.52	5	no
110166	3	2682626	2406700	6	65	59	60.56	58.56	3	no
110167	3	2682829	2406593	5	65	60	60.56	58.56	3	no
110168	3	2683040	2406454	6	64	58	54.51	52.51	0	yes
90149	5	2683141	2370724	143	3.88	-139.12	-108.83	-122.79	7	yes
G46	19	2683676	2364817	200	59.58	-140.42	-13.29	-56.53	22	yes
WWK7	23	2683864	2357055	799	51.5	-747.5	-721.54	-1221.5	23	no
86669	5	2684013	2386136	85	9	-76	-73.44	-81.29	5	no
92177	5	2684210	2394150	38	49	11	11.1	-3.26	5	no
86464	5	2685541	2378892	105	8	-97	-99.36	-111.68	4	yes
86670	4	2685542	2378884	59	8	-51	-19.53	-99.36	4	no
86726	3	2685548	2378915	12	8	-4	0.57	-19.53	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
G54	19	2685958	2367270	234	54	-180	-113.42	-162.36	20	yes
90148	5	2688532	2374035	106	3	-103	-81.79	-92.85	6	yes
105483	18	2688625	2351378	1029	28	-1001	-736.02	-738.02	21	yes
105484	5	2688656	2351346	52	28	-24	-20.12	-47	5	no
145091	5	2692353	2345871	0	1.99	n/a	-47.37	-63.28	5	no
109044	5	2693425	2391702	0	44.84	n/a	-11.44	-40.29	5	no
G66	22	2693472	2368179	801	6	-795	-688.26	-895.73	22	no
90400	15	2694503	2373976	787	0.73	-786.27	-682.64	-840.38	15	no
90366	16	2694529	2374029	830	0.73	-829.27	-840.38	-842.87	15	yes
86465	5	2694549	2380502	112	4.99	-107.01	-91.65	-114.1	5	no
86466	5	2694551	2380500	112	4.99	-107.01	-91.65	-114.1	5	no
77947	8	2700775	2386061	107	30.17	-76.83	-91.3	-100.86	6	yes
77945	18	2700814	2386079	775	30.17	-744.83	-721.9	-723.9	19	yes
105478	9	2708356	2411556	48	39	-9	-15.12	-17.12	5	yes
105479	2	2708360	2411571	13	39	26	29	-3.12	2	no
105392	2	2709725	2411335	22	37	15	30.5	-16.12	2	no
50876	5	2709899	2370039	57	5	-52	-50.62	-110.61	5	no
110177	9	2709953	2411714	39	37	-2	-28.12	-30.12	2	yes
145093	5	2710101	2362746	0	10	n/a	-34.85	-74.67	5	no
105477	2	2710822	2410369	3	28.23	25.23	23.91	-10.07	0	yes
56545	15	2711368	2394903	43	46.67	3.67	-371.08	-424.47	4	yes
105476	2	2711423	2411015	6	32	26	30.24	-1.97	2	no
56541	2	2711424	2409624	0	32	n/a	37.01	27.78	2	no
56546	2	2711451	2409610	5	32	27	37.01	27.78	3	yes
56548	9	2712147	2409756	6	30	24	0.79	-4.03	2	yes
56540	9	2712152	2409786	3	30	27	0.79	-4.03	2	yes
111800	9	2712155	2409797	58	30	-28	0.79	-4.03	14	yes
56539	9	2712249	2410310	5	31	26	-3.78	-7.43	0	yes
56536	9	2713306	2409284	4	26	22	9.28	2.13	2	yes
56537	9	2713402	2409814	5	26	21	0.4	-4.14	2	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
56550	9	2713411	2409842	6	26	20	0.4	-4.14	2	yes
56538	9	2713520	2410442	5	27	22	-2.57	-6.09	2	yes
56533	2	2714924	2409073	3	23	20	22.69	-5.37	2	no
56534	2	2715048	2409763	5	24	19	22.14	-17.1	2	no
56535	2	2715143	2410293	3	23	20	20.95	-7.22	2	no
90615	5	2716462	2376783	65	8	-57	-60.44	-89.95	4	yes
56531	2	2716561	2408898	3	21	18	20.33	-27.94	2	no
56532	2	2716677	2409530	4	23	19	19.94	-33.21	2	no
140692	5	2717298	2389460	69	26	-43	-20.03	-90.37	5	no
56744	2	2718291	2409242	4	19.95	15.95	19.03	-3.13	2	no
110165	2	2718609	2408008	4	18	14	19.2	-7.09	2	no
56530	2	2719538	2406888	4	17	13	19.89	3.52	2	no
56528	2	2719629	2407381	2	18	16	19	-4.99	2	no
56529	2	2719718	2407957	7	18	11	18.9	-7.89	2	no
105480	2	2720462	2407322	3	17	14	18	-3.82	2	no
80760	2	2721827	2406046	2	12	10	17	0.79	2	no
80761	2	2722005	2406657	4	15	11	17.96	-19.54	2	no
80762	2	2722108	2407287	2	15	13	17.84	-5.37	2	no
140279	2	2723314	2405478	6	11	5	18.25	-4.03	2	no
65762	5	2723813	2388361	71	25	-46	-23.71	-92.66	5	no
140281	15	2727673	2405062	0	8	n/a	-110.67	-127.08	15	no
140280	3	2728606	2406724	11	4.22	-6.78	-1.79	-22	3	no
105733	18	2730124	2408060	149	53	-96	-97.33	-117.05	17	yes
46968	5	2730196	2394362	36	37	1	-7.97	-50.85	4	yes
105725	30	2730404	2413138	0	28	n/a	-532.58	-732.58	30	no
47063	18	2730849	2396570	553	36	-517	-502.22	-507.36	20	yes
105728	18	2731009	2408220	132	30	-102	-69.75	-81.19	20	yes
65764	5	2731255	2389067	45	0	-45	-41.48	-80.4	5	no
105730	18	2732144	2408798	83	36	-47	-19.54	-30.56	20	yes
144468	3	2797767	2417344	15	6	-9	9.69	4.37	7	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
144469	30	2798169	2419147	31	3.14	-27.86	-47.19	-247.19	20	yes
115733	30	2798901	2418392	29	12	-17	-46.03	-246.03	15	yes
144467	15	2799610	2415561	32	14	-18	-20.92	-22.92	13	yes
115734	15	2801774	2416059	27	9	-18	-18.89	-20.89	14	yes
115732	15	2804218	2414545	29	7	-22	-24.46	-26.46	13	yes
41973	3	2660288	2376718	13.71	22	8.29	12.93	2.45	3	no
42001	2	2656732	2377395	10.05	23	12.95	27.18	16.01	3	yes
42002	3	2663477	2376112	14.32	19	4.68	11.7	-23.04	3	no
42003	3	2666460	2375529	10.66	23.95	13.29	15.47	-0.6	3	no
42004	3	2655966	2377510	14.63	26	11.37	17.64	-22.75	3	no
42005	2	2659365	2376894	12.49	23	10.51	34.08	13.2	3	yes
42006	3	2658709	2377052	16.15	25	8.85	14.34	2.49	3	no
42007	3	2665085	2375827	17.37	21	3.63	12.13	-22.33	3	no
42020	3	2660710	2376652	18.59	22	3.41	12.81	1.35	3	no
42026	3	2657303	2377286	19.2	24	4.8	14.15	-3.73	3	no
42027	3	2656397	2377442	18.89	22	3.11	16.75	-33.32	3	no
42028	3	2657317	2378300	18.89	21	2.11	18.33	-2.54	3	no
42038	3	2665681	2379023	13.71	21	7.29	18.75	6.25	3	no
42039	3	2658760	2378541	18.28	23	4.72	19.12	-15.77	3	no
42041	3	2665377	2377422	15.84	21	5.16	17	1.51	3	no
42045	2	2655864	2377547	10.97	26	15.03	27.12	17.64	3	yes
42051	4	2664100	2379330	44	22	-22	-1.06	-102.19	4	no
42058	3	2663738	2377525	20.42	20	-0.42	17.25	-0.61	3	no
42059	3	2654903	2385150	25.9	44.6	18.7	35.33	25.33	4	yes
42063	3	2657676	2379947	17.37	28	10.63	21.78	13.42	4	yes
42066	3	2667692	2380777	23.16	20.9	-2.26	18.3	2.21	4	yes
42067	3	2664453	2381417	32.61	23	-9.61	19.2	2.46	4	yes
42068	3	2662883	2381711	20.42	26	5.58	20.04	-29.95	3	no
42069	3	2661361	2381995	19.2	31.1	11.9	20.08	1.41	3	no
42070	3	2659404	2382358	14.93	30	15.07	22.79	10.44	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
42071	3	2657925	2382929	12.19	36	23.81	27.12	17.42	3	no
42072	3	2656373	2383538	15.24	37	21.76	29.85	20.25	3	no
42073	9	2655126	2384033	85	40	-45	-43.81	-74.33	9	no
42074	3	2656599	2384879	14.02	39	24.98	30.11	21.66	3	no
42075	3	2658253	2384589	17.67	37	19.33	28.51	20.1	4	yes
42076	3	2659861	2384312	13.1	32	18.9	25.19	15.77	3	no
42077	3	2661654	2383970	19.2	35	15.8	21.73	12.47	3	no
42078	3	2663670	2383687	18.89	28.99	10.1	19	-9.47	3	no
42079	3	2665061	2384478	18.59	28	9.41	18	-0.62	3	no
42080	2	2666693	2384226	10.05	28	17.95	19.95	17.95	3	yes
42081	3	2668281	2383852	14.93	26.24	11.31	12.78	0.14	3	no
42083	3	2669022	2379228	15.24	20	4.76	17	0.55	3	no
42084	3	2667005	2377117	15.24	21	5.76	16.53	5.54	3	no
42085	2	2656914	2386440	10.66	42	31.34	34.9	30.43	2	no
42086	3	2658488	2386159	18.89	37.7	18.81	26.62	21.66	4	yes
42087	3	2660108	2385873	18.89	37	18.11	23.27	18.41	4	yes
42088	3	2661859	2385103	18.89	34	15.11	20.95	16.13	4	yes
42095	3	2662487	2379615	22.25	26	3.75	22.95	-63.88	3	no
42108	2	2660954	2379913	10.97	27	16.03	30.01	20.39	3	yes
42117	3	2661090	2378288	18.89	22.22	3.33	19.61	-11.72	3	no
42118	3	2662146	2377826	14.1	20	5.9	19.19	-3.53	3	no
42121	3	2670362	2377738	11.27	20.98	9.71	16.48	-7.34	3	no
42122	3	2671190	2381876	14.32	23	8.68	14.8	-7.23	3	no
42123	2	2672604	2380876	9.14	18	8.86	12.99	10.99	3	yes
42128	3	2672289	2378975	13.41	18	4.59	13.11	-21.44	3	no
42134	2	2665666	2374594	11.35	18	6.65	16.79	11.33	3	yes
42135	2	2665652	2374445	6.75	18	11.25	16.51	10.74	2	no
42136	2	2666359	2374612	9.8	17	7.2	16.03	11.14	3	yes
42137	2	2667385	2374192	9.8	18	8.2	18.82	12.87	3	yes
42181	5	2664919	2374924	110	17	-93	-65.8	-89.72	6	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
45962	18	2643354	2317957	229.3	2	-227.3	-178.77	-180.77	21	yes
50867	3	2708672	2372152	6.55	5	-1.55	-2.05	-21.08	2	yes
50868	2	2708672	2372152	2.8	5	2.2	2.19	-2.05	0	yes
50870	3	2709643	2369543	23	10	-13	1.25	-13.49	3	no
50871	3	2708309	2372760	21.3	0.1	-21.2	-2.69	-20.93	4	yes
50872	3	2709643	2369543	23	10	-13	1.25	-13.49	3	no
50877	2	2708309	2372760	4.75	0.1	-4.65	1.05	-2.69	3	yes
50878	2	2708309	2372760	1.9	0.1	-1.8	1.05	-2.69	2	no
50891	2	2708794	2371999	3	3	0	2.83	-2.06	2	no
51535	3	2683008	2406070	20	69	49	53.86	51.03	4	yes
51539	2	2682716	2405765	10.4	63	52.6	53.76	51.76	2	no
51575	2	2682229	2405778	10.66	61	50.34	51.09	49.09	2	no
51590	3	2682263	2405901	13.41	61	47.59	49.09	47.09	3	no
51592	2	2682001	2405356	28	60	32	48.89	46.89	10	yes
52872	3	2680268	2383579	25	15	-10	9.99	-26.28	3	no
52873	3	2677763	2383982	20	20	0	9.91	-23.45	3	no
52874	3	2679068	2380040	20	16	-4	9.24	-22.87	3	no
52875	3	2679451	2381595	17.5	15	-2.5	9.77	-24.31	3	no
52877	3	2675601	2387655	14.87	15.71	0.84	15.61	-0.36	3	no
52878	2	2675601	2387655	5.95	15.71	9.76	18.15	15.61	3	yes
52879	3	2680560	2386750	13.97	21	7.03	12.84	-29.28	3	no
52880	2	2680560	2386750	10.02	21	10.98	18.59	12.84	3	yes
52882	3	2677763	2383982	12.69	20	7.31	9.91	-23.45	3	no
52883	2	2677763	2383982	5.42	20	14.58	15.01	9.91	2	no
52885	2	2680268	2383579	7.08	15	7.92	14.8	9.99	3	yes
52886	2	2680268	2383579	4.99	15	10.01	14.8	9.99	2	no
52888	3	2679068	2380040	13.34	16	2.66	9.24	-22.87	3	no
52889	3	2679068	2380040	10.78	16	5.22	9.24	-22.87	3	no
52890	2	2679068	2380040	5.09	16	10.91	11.24	9.24	2	no
52891	3	2676431	2380996	13.86	11	-2.86	6.98	-23.61	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
52892	2	2676431	2380996	4.89	11	6.11	9.06	6.98	3	yes
52893	2	2679451	2381595	10.18	15	4.82	11.77	9.77	3	yes
52894	2	2679451	2381595	5.42	15	9.58	11.77	9.77	3	yes
56497	18	2680887	2368715	774.14	27	-747.14	-501.13	-554.29	23	yes
56547	9	2711758	2409462	13	30	17	8.55	2.22	4	yes
56549	9	2712564	2409113	12	31	19	3.72	-3.28	2	yes
56551	9	2713298	2409256	14	26	12	9.28	2.13	7	yes
56552	2	2718110	2408193	10	19	9	19.27	-11.97	2	no
56553	2	2718243	2408935	11	19.95	8.95	19.03	-3.13	2	no
58935	9	2666399	2375524	862	17	-845	-183.86	-185.86	23	yes
59328	2	2664419	2381449	5.36	22.82	17.46	21.32	19.32	3	yes
59329	3	2664567	2382021	10.05	24	13.95	19.05	0.32	3	no
59330	2	2664567	2382021	5.41	24	18.59	21.05	19.05	3	yes
59331	2	2665106	2384501	4.99	28	23.01	20	18	0	yes
59336	2	2657303	2377286	6.17	24	17.83	28.98	14.15	2	no
59337	2	2657339	2377269	3.02	24	20.98	28.98	14.15	2	no
60082	9	2643050	2326627	30.5	21	-9.5	-37.39	-39.39	6	yes
66881	9	2621756	2359451	100	14	-86	-1.56	-3.56	15	yes
76860	3	2669776	2396182	20.13	33	12.87	29.16	26.24	7	yes
76888	3	2666044	2395310	25	38	13	33.58	27.9	7	yes
76891	3	2669776	2396182	10.08	33	22.92	29.16	26.24	5	yes
76892	2	2669776	2396182	5.75	33	27.25	33.08	29.16	3	yes
76894	2	2665829	2397604	5	40	35	39.87	31.37	2	no
76895	2	2666044	2395310	10.3	38	27.7	35.58	33.58	4	yes
76896	2	2666044	2395310	5.45	38	32.55	35.58	33.58	3	yes
77914	2	2700547	2381991	10.7	1.1	-9.6	4.4	-2.21	3	yes
77915	3	2705710	2383644	21	10.81	-10.19	4.71	-24.78	3	no
77918	3	2705591	2382981	19	10	-9	1.12	-23.36	3	no
77919	3	2705591	2382981	10.01	10	-0.01	1.12	-23.36	3	no
77920	2	2705591	2382981	6.65	10	3.35	7.69	1.12	2	no

2.6.2.7.1 Observation bore data

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
77921	3	2705632	2383248	18.75	10	-8.75	1.12	-23.36	3	no
77922	2	2705632	2383248	12.02	10	-2.02	7.69	1.12	3	yes
77924	3	2705470	2382325	19	3.58	-15.42	-6.09	-20.77	3	no
77925	2	2705470	2382325	10.31	3.58	-6.73	4.74	-6.09	3	yes
77926	2	2705470	2382325	5.63	3.58	-2.05	4.74	-6.09	2	no
77927	3	2705284	2381449	20.97	1.6	-19.37	-8.65	-19.72	3	no
77928	2	2705284	2381449	10.23	1.6	-8.63	1.8	-8.65	2	no
77929	2	2705284	2381449	5.49	1.6	-3.89	1.8	-8.65	2	no
77930	3	2702941	2383982	21.28	22.68	1.4	13.11	-23.18	3	no
77933	3	2702676	2383292	21.28	17.66	-3.62	3.09	-19.4	3	no
77936	3	2702580	2382756	21.7	4	-17.7	-1.02	-18.41	3	no
77937	3	2702580	2382756	9.7	4	-5.7	-1.02	-18.41	3	no
77938	2	2702580	2382756	4.91	4	-0.91	9.6	-1.02	2	no
77939	3	2702476	2382096	21.14	1	-20.14	-6.67	-16.77	4	yes
77940	2	2702476	2382096	10.27	1	-9.27	5.59	-6.67	3	yes
77941	2	2702476	2382096	4.92	1	-3.92	5.59	-6.67	2	no
77942	3	2702281	2381024	21.35	1	-20.35	-7.94	-14.64	4	yes
77943	2	2702281	2381024	10.27	1	-9.27	2.14	-7.94	3	yes
77944	2	2702281	2381024	4.92	1	-3.92	2.14	-7.94	2	no
80866	2	2721083	2407535	10	18	8	18	-7.35	2	no
86653	3	2697822	2382551	19.37	1.69	-17.68	-2.8	-15.49	4	yes
86654	3	2695174	2379864	20	2.42	-17.58	-2.05	-19.29	3	no
86655	3	2695174	2379864	9.23	2.42	-6.81	-2.05	-19.29	3	no
86656	3	2691898	2378707	21	4	-17	-1.17	-20.33	3	no
86657	2	2691898	2378707	4.77	4	-0.77	2.68	-1.17	2	no
86658	3	2690815	2379555	20	3	-17	-0.17	-21.44	3	no
86659	2	2690815	2379555	5.4	3	-2.4	5.31	-0.17	3	yes
86660	3	2688409	2379916	17.26	5	-12.26	0.01	-21.91	3	no
86661	2	2688409	2379916	4.77	5	0.23	6.8	0.01	2	no
86662	3	2687427	2380215	20.5	8	-12.5	-0.05	-22.74	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
86663	2	2687427	2380215	5.26	8	2.74	7.75	-0.05	2	no
86664	3	2692667	2380142	10.25	6	-4.25	-1.91	-21.28	3	no
86665	2	2692667	2380142	5.6	6	0.4	5.13	-1.91	2	no
86666	3	2695267	2384265	19.74	1.33	-18.41	-3.31	-18.98	3	no
86667	2	2695267	2384265	5.65	1.33	-4.32	3.5	-3.31	3	yes
86725	4	2685548	2378915	50	8	-42	-19.53	-99.36	4	no
86727	2	2685548	2378915	8	8	0	5	0.57	3	yes
86736	3	2697822	2382551	13.45	1.69	-11.76	-2.8	-15.49	3	no
86737	2	2697822	2382551	4.53	1.69	-2.84	2.6	-2.8	3	yes
86739	3	2682856	2379347	12.45	10	-2.45	5.99	-20.27	3	no
86740	2	2682856	2379347	5.66	10	4.34	7.99	5.99	3	yes
86741	3	2694215	2383036	16.49	1.65	-14.84	-7.77	-21.12	3	no
86742	2	2694215	2383036	9.33	1.65	-7.68	3.86	-7.77	2	no
86743	2	2694215	2383036	5.5	1.65	-3.85	3.86	-7.77	2	no
86744	3	2689996	2382237	25.25	7	-18.25	-3.17	-26.23	3	no
86745	2	2689996	2382237	9.73	7	-2.73	6.73	-3.17	2	no
86746	2	2689996	2382237	5.23	7	1.77	6.73	-3.17	2	no
86747	3	2685658	2384116	17.4	11	-6.4	0.01	-31.08	3	no
86748	2	2685658	2384116	6.51	11	4.49	9	0.01	2	no
86749	2	2685658	2384116	6.45	11	4.55	9	0.01	2	no
89810	30	2651492	2369190	702.02	35	-667.02	-3440.4	-3640.4	23	yes
89818	3	2658117	2369716	22.55	18	-4.55	10.15	6.4	6	yes
89841	2	2657221	2369554	9.3	17	7.7	17.45	11.15	4	yes
89842	2	2657221	2369554	5.32	17	11.68	17.45	11.15	2	no
89845	3	2658117	2369716	30	18	-12	10.15	6.4	6	yes
89850	2	2660328	2370169	4.75	13.94	9.19	18.32	9.69	3	yes
90138	18	2694513	2374002	1049.8	0.73	-1049.03	-845.36	-847.36	22	yes
90357	3	2691134	2372094	21.6	0.02	-21.58	-4.62	-28.95	3	no
90358	2	2691134	2372094	10.34	0.02	-10.32	2	-4.62	3	yes
90359	2	2691134	2372094	6.57	0.02	-6.55	2	-4.62	3	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
90360	3	2691200	2375245	20	3	-17	-1.18	-44.15	3	no
90361	2	2691200	2375245	5.84	3	-2.84	2.24	-1.18	3	yes
90423	3	2683852	2373197	21.17	13	-8.17	0.11	-39.77	3	no
90424	3	2684537	2374124	21.5	11	-10.5	0.55	-42.78	3	no
90428	3	2686816	2373735	14.07	7	-7.07	-0.03	-55.51	3	no
90429	2	2686816	2373735	10.34	7	-3.34	5	-0.03	3	yes
90430	2	2686816	2373735	5.12	7	1.88	5	-0.03	2	no
90431	3	2688593	2373773	21.55	3	-18.55	-2.66	-63.71	3	no
90432	2	2688493	2373775	10.71	3	-7.71	3.89	-2.66	3	yes
90433	2	2688493	2373775	5.3	3	-2.3	3.89	-2.66	2	no
90434	3	2688607	2374448	22.04	4	-18.04	-2.02	-59.4	3	no
90435	2	2688607	2374448	8.15	4	-4.15	3.98	-2.02	3	yes
90436	2	2688607	2374448	4.44	4	-0.44	3.98	-2.02	2	no
90437	3	2694679	2374109	15.7	0.73	-14.97	-2.32	-29.1	3	no
90438	3	2694679	2374109	11.05	0.73	-10.32	-2.32	-29.1	3	no
90439	3	2694679	2374109	6.32	0.73	-5.59	-2.32	-29.1	3	no
90614	18	2716462	2376783	1246.4	8	-1238.39	-1014.5	-1016.5	22	yes
92296	4	2680164	2396489	33	38	5	10.63	-21.78	4	no
92297	3	2680164	2396489	15	38	23	25.57	10.63	3	no
94805	3	2569818	2312072	11.5	6.9	-4.6	7.44	4.91	7	yes
94806	3	2569395	2313647	10	5	-5	-5.49	-7.5	2	yes
94808	3	2568601	2314320	10	8.95	-1.05	4.41	2.18	5	yes
94809	3	2568284	2313546	11.5	13.08	1.58	7.71	5.37	5	yes
94810	3	2568745	2313304	22	18.73	-3.27	1.9	-0.2	5	yes
94811	3	2568572	2313057	26.5	18.73	-7.77	1.9	-0.2	7	yes
95196	18	2660434	2394286	96	75.09	-20.91	34.87	32.87	23	yes
95401	2	2672432	2385695	5.22	23	17.78	13.05	11.05	0	yes
95485	4	2667519	2388050	34	26	-8	11.47	-30.89	4	no
95486	3	2667529	2388049	15	26	11	15.43	11.47	4	yes
95487	3	2661349	2388017	41	42	1	30.82	27.22	7	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
95488	9	2662140	2392315	28	36.74	8.74	17.58	11.8	10	yes
95489	8	2665364	2393361	33	38.06	5.06	10.66	5.47	9	yes
95491	2	2665364	2393361	8.81	38.06	29.25	34.96	29.64	3	yes
95492	2	2665364	2393361	6.51	38.06	31.55	34.96	29.64	2	no
95493	2	2669865	2390902	8.39	29	20.61	23.25	20.52	2	no
95494	2	2669865	2390902	5.49	29	23.51	23.25	20.52	0	yes
95495	2	2671771	2395185	8.35	27	18.65	27.4	23.75	5	yes
95496	2	2671771	2395185	5.48	27	21.52	27.4	23.75	4	yes
95497	3	2669041	2386192	17.4	26	8.6	13.78	4.02	3	no
95498	2	2669041	2386192	8.35	26	17.65	15.78	13.78	0	yes
95499	2	2669041	2386192	5.48	26	20.52	15.78	13.78	0	yes
95500	3	2665108	2386529	19.53	27.45	7.92	16.89	-27.41	3	no
95501	2	2665108	2386529	7.69	27.45	19.76	18.89	16.89	0	yes
95502	2	2665108	2386529	4.89	27.45	22.56	18.89	16.89	0	yes
95503	3	2661349	2388017	18.69	42	23.31	30.82	27.22	5	yes
95504	2	2662140	2392315	8.87	36.74	27.87	40.74	29.58	3	yes
95505	2	2662140	2392315	5.45	36.74	31.29	40.74	29.58	2	no
96560	18	2635010	2366948	583	34.78	-548.22	-518.07	-546.7	19	yes
98114	8	2674804	2400464	26	35	9	12.82	6.85	8	no
98115	3	2672955	2397251	42	73	31	50.49	40.73	4	yes
98119	3	2679319	2389598	19.2	21	1.8	11.61	-19.48	3	no
98120	2	2679319	2389598	10.8	21	10.2	18.99	11.61	3	yes
98121	2	2679319	2389598	4.68	21	16.32	18.99	11.61	2	no
98122	2	2679053	2391234	9.63	19	9.37	18.17	13.35	3	yes
98123	2	2679053	2391234	4.24	19	14.76	18.17	13.35	2	no
98124	2	2675572	2397024	5.31	30	24.69	31.02	27.85	4	yes
98125	3	2674794	2400454	14.01	35	20.99	30.77	28.77	6	yes
98126	3	2674794	2400454	10.88	35	24.12	30.77	28.77	6	yes
98127	2	2674794	2400454	3.81	35	31.19	38.88	30.77	2	no
103582	9	2653126	2384365	460.33	61	-399.33	-47.98	-77.14	20	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
103583	18	2651685	2375860	727.67	21	-706.67	-617.23	-619.23	23	yes
103734	3	2653116	2375225	20	18	-2	8.08	-1.97	4	yes
103825	2	2653051	2375271	10.44	18	7.56	18.1	8.08	3	yes
103826	2	2653116	2375225	4.86	18	13.14	18.1	8.08	2	no
103828	2	2655864	2377547	7.47	26	18.53	27.12	17.64	2	no
104537	4	2673518	2327830	39	4	-35	-14.28	-31.29	5	yes
105199	3	2674346	2378582	20.46	14	-6.46	9.44	-25.41	3	no
105200	2	2674334	2378590	9.4	14	4.6	11.91	9.44	3	yes
105201	2	2674346	2378582	5.43	14	8.57	11.91	9.44	3	yes
109039	9	2698908	2386140	121.92	4	-117.92	-98.96	-168.22	9	no
110199	2	2689066	2378191	9	2	-7	3.81	0.04	3	yes
110201	2	2688604	2380983	8.3	7	-1.3	8.53	-0.04	3	yes
110206	3	2688274	2379098	13.4	4	-9.4	-0.02	-20.8	3	no
110208	3	2688163	2378590	10.95	4	-6.95	-0.04	-20.53	3	no
110720	18	2659138	2338232	333	92.79	-240.21	-116.22	-118.22	21	yes
110727	9	2600232	2365476	193.3	69.46	-123.84	-19.58	-32.9	16	yes
110728	3	2600200	2365480	80	69.46	-10.54	60.55	47.19	8	yes
110732	9	2651454	2369213	400.2	35	-365.2	-119.14	-139.12	14	yes
110733	9	2661081	2370219	373.2	15	-358.2	-189.05	-272.22	13	yes
110749	3	2695267	2384265	10.47	1.33	-9.14	-3.31	-18.98	3	no
110976	9	2710822	2410345	116	28.23	-87.77	-22.07	-24.29	23	yes
110978	9	2708309	2411580	74.5	39	-35.5	-15.12	-17.12	19	yes
112982	2	2688703	2369493	9	11	2	6.75	-2.19	2	no
112983	2	2688703	2369493	5.1	11	5.9	6.75	-2.19	2	no
112984	3	2688480	2368397	12.95	19	6.05	12.04	1.79	3	no
112987	3	2694523	2370272	13.3	1	-12.3	-2.2	-34.72	3	no
112988	3	2694523	2370272	10.25	1	-9.25	-2.2	-34.72	3	no
112989	2	2694523	2370272	5.05	1	-4.05	1.24	-2.2	3	yes
112991	2	2677658	2377230	11.17	5	-6.17	7.59	-0.93	3	yes
112992	2	2677658	2377230	4.78	5	0.22	7.59	-0.93	2	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
112993	3	2679253	2372193	13.46	5	-8.46	-1.29	-30.79	3	no
112994	2	2679253	2372193	4.77	5	0.23	8.09	-1.29	2	no
112995	3	2672975	2373426	20.45	9	-11.45	6	-48.26	3	no
112996	3	2650006	2374078	19.32	25	5.68	9.94	0.82	3	no
112997	3	2652942	2367743	9.37	37	27.63	21.54	17.7	0	yes
112998	3	2648550	2363533	22.05	61	38.95	40.67	26.92	3	no
113000	3	2665385	2369383	21.69	11.98	-9.71	9.78	-37.35	3	no
113668	30	2571699	2310853	50	11.32	-38.68	-742.42	-942.42	23	yes
113669	3	2571699	2310854	19	11.32	-7.68	7.61	5.61	10	yes
114155	30	2571699	2310855	32	11.32	-20.68	-742.42	-942.42	17	yes
114159	3	2568204	2315100	50	9.56	-40.44	1.66	-0.34	23	yes
114160	3	2568203	2315099	23	9.56	-13.44	1.66	-0.34	10	yes
115218	2	2684708	2384637	14.3	16	1.7	10.49	2.74	3	yes
115220	3	2687560	2378473	15.7	7	-8.7	-0.07	-19.73	3	no
115221	3	2684421	2379069	14.1	9	-5.1	3.3	-20.31	3	no
115223	3	2686471	2376614	14.6	8	-6.6	0.16	-22.78	3	no
115225	3	2686471	2376614	20.6	8	-12.6	0.16	-22.78	3	no
115226	3	2687049	2376502	16.7	7	-9.7	0.12	-27.43	3	no
115245	2	2687049	2376502	8.9	7	-1.9	5.01	0.12	3	yes
115630	3	2681968	2379501	13.33	11	-2.33	7.31	-21.2	3	no
115631	3	2681856	2378923	12.91	12.98	0.07	7.95	-20.58	3	no
115937	3	2664427	2381049	20.5	26	5.5	19.64	-6.78	3	no
115939	3	2661734	2384545	20.5	33	12.5	21.05	14.9	4	yes
115940	3	2667702	2380907	20.5	20.9	0.4	18.3	2.21	4	yes
115941	3	2667877	2381778	20.5	23	2.5	18.78	1.67	3	no
119103	3	2654568	2320729	0	3	n/a	-0.1	-29.35	3	no
119104	2	2654573	2320724	0	3	n/a	7.18	-0.1	2	no
119105	2	2654573	2320719	0	3	n/a	7.18	-0.1	2	no
119106	2	2654559	2320689	0	3	n/a	7.18	-0.1	2	no
119107	2	2654568	2320675	0	3	n/a	7.18	-0.1	2	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
119108	2	2656313	2319385	0	5	n/a	2.75	-2.45	2	no
119109	3	2656307	2319382	0	5	n/a	-2.45	-47.77	3	no
119110	3	2656423	2323075	0	12.13	n/a	6.2	-18.69	3	no
119113	3	2665743	2321355	0	8	n/a	0.03	-30.19	3	no
119114	2	2665745	2321356	0	8	n/a	3.76	0.03	2	no
119115	3	2667011	2326948	0	16	n/a	9.09	-13.19	3	no
119116	2	2667424	2323704	0	8	n/a	5.58	-0.24	2	no
119117	3	2667422	2323704	0	8	n/a	-0.24	-27.87	3	no
119118	2	2662140	2321449	0	7	n/a	8.56	0.01	2	no
119119	2	2662139	2321453	0	7	n/a	8.56	0.01	2	no
119120	2	2661150	2321142	0	5	n/a	6.64	0.01	2	no
119121	2	2661149	2321138	0	5	n/a	6.64	0.01	2	no
119122	2	2672405	2328230	0	2	n/a	5.68	-0.19	2	no
119123	3	2672405	2328228	0	2	n/a	-0.19	-11.56	3	no
119132	2	2665655	2322353	0	7	n/a	4.76	0.02	2	no
119136	3	2645306	2320962	0	13	n/a	9.5	1.25	3	no
119137	3	2649317	2332391	0	58.81	n/a	46.22	44.22	3	no
119138	3	2649029	2332819	0	50	n/a	47.1	45.1	3	no
119892	3	2689529	2379798	12.2	7.3	-4.9	0.02	-21.79	3	no
120793	3	2692906	2373778	25	4	-21	-1.5	-48.88	3	no
120794	3	2694222	2373580	20.5	3.99	-16.51	-1.57	-42.03	3	no
120795	3	2694065	2373223	20.5	2.53	-17.97	-2.02	-48.77	3	no
120796	3	2693678	2379595	14.5	2.45	-12.05	-1.69	-19.13	3	no
120799	3	2693873	2378891	20.5	0.98	-19.52	-0.49	-16.9	4	yes
120800	3	2693714	2378464	20.5	3	-17.5	-1.57	-15.9	4	yes
120801	3	2692396	2378572	13	3.99	-9.01	-1.83	-19.97	3	no
120802	3	2692561	2379289	12	0	-12	-1.02	-19.91	3	no
120997	3	2693233	2384648	18.1	2.23	-15.87	-3.95	-22.48	3	no
121802	3	2709866	2386171	23.5	20.96	-2.54	11.46	-21.26	3	no
121803	3	2712227	2383520	25	3	-22	-5.46	-23.46	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
121804	3	2706711	2384376	20.5	18	-2.5	9.37	-26.33	3	no
121805	3	2713407	2388988	25	14	-11	14.52	-9.51	4	yes
121806	3	2718562	2384778	16	10	-6	-7.28	-24.99	2	yes
121807	3	2715586	2387942	19.5	15	-4.5	8.06	-14.61	3	no
121808	3	2725593	2389414	23.5	14	-9.5	9.83	-4.8	4	yes
121809	3	2719211	2388067	20.5	29	8.5	13.79	-9.24	3	no
121810	3	2723768	2388272	20.5	25	4.5	17.31	-8.01	3	no
122449	2	2710505	2385647	3	5	2	6.66	-0.69	2	no
122450	3	2710505	2385647	14.5	5	-9.5	-0.69	-20.3	3	no
122451	2	2713007	2384714	6.1	3	-3.1	3.99	-4.77	2	no
122452	2	2712403	2380704	7	4	-3	1.02	-1.9	3	yes
122453	2	2716187	2382226	2	4	2	1	-2.86	0	yes
122454	2	2722295	2387202	5	5	0	16.81	-3.02	2	no
122455	2	2722295	2387202	9	5	-4	16.81	-3.02	3	yes
122456	3	2722295	2387202	20	5	-15	-3.02	-10.5	4	yes
122457	2	2718869	2386073	5	6	1	10.82	-7.6	2	no
122458	2	2718869	2386073	10	6	-4	10.82	-7.6	2	no
122459	3	2718869	2386073	16	6	-10	-7.6	-18.77	3	no
122461	3	2711719	2388674	16.79	6	-10.79	9.87	-13.53	3	no
122462	3	2711719	2388674	9.74	6	-3.74	9.87	-13.53	3	no
122463	3	2711719	2388674	20.99	6	-14.99	9.87	-13.53	4	yes
122464	3	2711724	2388924	20	6	-14	9.87	-13.53	4	yes
122465	3	2711070	2388737	20	5.49	-14.51	6.86	-16.4	3	no
122466	3	2710709	2388244	20.43	10	-10.43	2.69	-18.51	3	no
122467	3	2713574	2388885	10.8	6	-4.8	1.59	-10.61	3	no
122468	2	2713572	2388785	5.48	6	0.52	15.89	1.59	3	yes
122469	2	2713570	2388685	5.13	6	0.87	15.89	1.59	3	yes
122470	3	2723300	2387431	16.03	5	-11.03	-1.9	-11.58	3	no
122471	2	2723300	2387431	9.49	5	-4.49	17.05	-1.9	3	yes
122472	2	2723300	2387431	5.51	5	-0.51	17.05	-1.9	2	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
122473	3	2723820	2388371	20.83	25	4.17	17.31	-8.01	3	no
123721	3	2666401	2388173	13	28	15	20	5.89	3	no
126436	3	2680435	2380824	35	14	-21	9	-23.44	3	no
126437	3	2683019	2380474	16.5	11	-5.5	6.57	-21.25	3	no
127134	3	2691340	2376422	18.6	3	-15.6	-0.98	-26.57	3	no
127135	3	2691388	2376792	17.4	5	-12.4	-1	-23.31	3	no
127137	3	2691496	2377180	17	3	-14	-0.99	-21.34	3	no
127144	3	2691546	2377639	14	3	-11	-0.92	-20.57	3	no
127302	3	2672127	2378746	14.5	16	1.5	13.25	-22.33	3	no
127303	3	2672568	2378922	11	16	5	12.42	-23.8	3	no
127611	3	2711712	2388364	15	6.49	-8.51	-1.48	-14.91	3	no
127612	2	2711712	2388364	5	6.49	1.49	9.79	-1.48	2	no
127613	2	2692110	2383070	5	1	-4	4.99	-6.32	2	no
127614	2	2693807	2383355	5	0	-5	3.86	-7.5	2	no
127615	3	2693807	2383355	15	0	-15	-7.5	-21.61	3	no
127616	3	2693467	2378149	15	1.99	-13.01	-0.26	-16.74	3	no
127617	3	2693467	2378149	5	1.99	-3.01	-0.26	-16.74	3	no
127618	3	2692431	2375009	15	3	-12	-1.43	-35.6	3	no
127619	3	2692431	2375009	5	3	-2	-1.43	-35.6	3	no
127620	3	2692110	2383070	14	1	-13	-6.32	-24.35	3	no
127621	3	2694724	2372669	15	1.65	-13.35	-2.67	-49.33	3	no
127622	3	2694724	2372669	5	1.65	-3.35	-2.67	-49.33	3	no
127623	3	2687929	2370740	15	0	-15	-4.04	-25.34	3	no
127624	2	2687929	2370740	5	0	-5	2.35	-4.04	3	yes
127625	3	2690899	2369227	15	6.94	-8.06	-1.46	-11.45	3	no
127626	2	2690899	2369227	5	6.94	1.94	1.22	-1.46	0	yes
127896	3	2681312	2380655	16	14	-2	8	-23.1	3	no
127897	3	2680684	2380769	16	13	-3	8.85	-23.38	3	no
127898	3	2679957	2380904	17.5	15	-2.5	9	-23.5	3	no
127899	3	2680219	2379107	19	14	-5	8.9	-21.64	3	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
127996	3	2691992	2379361	13	3	-10	-1.19	-20.96	3	no
127997	3	2691564	2380430	11.5	4	-7.5	-1.5	-21.97	3	no
128028	3	2648483	2373659	13	25	12	11.38	2.9	2	yes
128029	3	2646285	2372498	20.5	27	6.5	19.16	8.09	4	yes
128030	3	2644525	2372823	15	29	14	20.08	12.95	3	no
128031	3	2641280	2373330	19	34	15	28.93	19.56	4	yes
128033	3	2641613	2374433	14.5	38	23.5	30.94	23.18	3	no
129031	3	2664660	2382406	12.5	25	12.5	19	-1.58	3	no
129032	3	2664851	2383490	12	28	16	18	-1.21	3	no
130367	3	2673705	2387669	11	20	9	14.93	5.93	3	no
130368	3	2674095	2384349	10	16	6	9.97	-9.13	3	no
130369	2	2668751	2391936	11.6	31	19.4	27.74	22.9	3	yes
130370	2	2671345	2393012	10	26	16	25.2	19.94	3	yes
130371	2	2669928	2394623	10	31	21	29.66	23	3	yes
130372	2	2671415	2388238	11.75	26	14.25	19.04	17.04	3	yes
130373	2	2662613	2395537	7	45	38	44.15	31.61	2	no
130374	2	2667404	2389723	11	29.99	18.99	20.92	18.92	2	no
131246	3	2675496	2383379	10.5	13	2.5	9.88	-18.28	3	no
131249	3	2679167	2393348	13	23	10	18.95	-4.87	3	no
131250	2	2676821	2395499	10	28	18	26.36	21.36	4	yes
131253	3	2666038	2389942	10	28	18	22.73	20.73	5	yes
131255	2	2674784	2403816	6.5	44	37.5	37.83	35.83	2	no
131257	2	2668746	2395008	11	32	21	30.7	26.82	4	yes
131259	3	2684843	2382953	14	13	-1	2.08	-29.14	3	no
135289	2	2682217	2383238	10	15	5	12.15	9.04	3	yes
135416	3	2684086	2377895	17.5	11	-6.5	2.5	-20.9	3	no
136519	3	2678617	2383364	18	18	0	9.9	-25.01	3	no
136529	3	2678970	2380154	20.5	16	-4.5	9	-23.29	3	no
136531	3	2678981	2380174	21	16	-5	9	-23.29	3	no
136533	3	2678125	2381843	19	17	-2	9.1	-24.3	3	no

2.6.2.7.1 Observation bore data

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
136537	3	2683171	2378175	10.97	13	2.03	5.01	-19.93	3	no
136539	3	2681699	2383359	24	13	-11	9.66	-26.34	3	no
136540	3	2685888	2380789	14.5	8	-6.5	0.52	-23.4	3	no
136718	3	2693543	2376046	20.5	2.93	-17.57	-1.88	-17.49	4	yes
136719	2	2693553	2376046	5.9	2.93	-2.97	1	-1.88	3	yes
136999	3	2665923	2381163	20	25.5	5.5	20.09	7.94	4	yes
137476	2	2678696	2383792	7.5	18	10.5	15.19	10.02	2	no
137478	3	2681548	2383312	14	15	1	9.79	-26.04	3	no
137479	2	2681553	2383312	7	15	8	12.99	9.79	3	yes
137481	3	2678679	2380090	20	15	-5	8.67	-22.95	3	no
137539	3	2678696	2383782	18	18	0	10.02	-25.05	3	no
139365	2	2654096	2374994	18	19	1	22.15	9.95	3	yes
139366	3	2651180	2374394	20	18	-2	9.62	0.81	4	yes
139367	3	2653588	2375115	14	17	3	8.9	-2.59	3	no
139370	3	2650900	2375697	20	25	5	15.63	8.15	4	yes
139374	3	2655426	2376387	30	22	-8	11.35	-31.02	3	no
139379	3	2665260	2386009	19	27	8	16.63	-12.6	3	no
139380	3	2660191	2386345	17	35	18	23.3	19.29	4	yes
139381	3	2656390	2387026	15	39	24	30.19	25.47	4	yes
140201	3	2667171	2387227	13.7	24	10.3	19.78	0.75	3	no
140202	3	2677244	2373096	15	4	-11	-3.91	-22.9	3	no
140204	3	2676701	2372493	13	3	-10	-4.19	-31.01	3	no
140213	3	2666872	2387253	16	24	8	19.78	0.75	3	no
140277	3	2678206	2371734	17	8	-9	-5.65	-32.03	3	no
140691	5	2709255	2389826	80	17	-63	-30.43	-56.65	7	yes
143099	3	2654794	2389638	22	46	24	42.25	36.28	6	yes
143100	2	2654794	2389638	6	46	40	46	42.25	3	yes
143101	2	2655890	2389618	8.3	42	33.7	47.21	35.72	3	yes
143102	3	2655895	2389615	21	42	21	35.72	31.18	6	yes
143103	3	2653131	2389533	8	56	48	45.68	41.51	0	yes

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
143104	3	2652817	2389800	8.3	54	45.7	48.77	44.86	3	no
143747	3	2686847	2383581	15	3.49	-11.51	-0.57	-30.24	3	no
143748	2	2685426	2384541	10	5	-5	9.01	0.11	3	yes
143749	3	2684009	2386122	9	7.69	-1.31	5.56	-31.49	3	no
144943	3	2668684	2396519	11	33	22	28.47	25.37	5	yes
145207	3	2681633	2375102	27	14	-13	0.64	-22.26	3	no
145214	2	2681633	2375102	27	14	-13	6.98	0.64	3	yes
145215	3	2680897	2377188	19.5	13.93	-5.57	1.8	-20.49	3	no
145216	2	2680897	2377188	19.5	13.93	-5.57	9.3	1.8	3	yes
145217	3	2683658	2376258	20	13	-7	1.71	-24.76	3	no
145218	2	2683658	2376258	20	13	-7	8.13	1.71	3	yes
145219	3	2682544	2377315	22	11	-11	3.11	-21.03	3	no
145220	2	2682544	2377315	22	11	-11	9	3.11	3	yes
WRK059121	18	2642696	2334157	23	71.73	48.73	19.65	12.54	3	yes
Sole1	18	2853712	2368609	n/a	0	n/a	-795.3	-1376.6	18	no
Scallop1	18	2814360	2359237	n/a	0	n/a	-1697.4	-2131.5	18	no
Grunter1	18	2807716	2353253	n/a	0	n/a	-1987.6	-2463.6	18	no
Patricia1	18	2802636	2380240	n/a	0	n/a	-701.47	-727.65	18	no
Flounder1	18	2799462	2348982	n/a	0	n/a	-2000.3	-2640.5	18	no
Tuna1	18	2799392	2364629	n/a	0	n/a	-1324.7	-1662.4	18	no
SpermWhale1	18	2795214	2377488	n/a	0	n/a	-822.87	-847	18	no
Kahawai1	18	2795163	2364658	n/a	0	n/a	-1403.5	-1766.4	18	no
Mackerel1	18	2792860	2330670	n/a	0	n/a	-2551	-3272	18	no
Halibut2	18	2790885	2339980	n/a	0	n/a	-2342	-3122.3	18	no
Anemone1A	18	2789397	2299109	n/a	0	n/a	-2597.8	-2933.1	18	no
Marlin2	18	2788238	2358496	n/a	0	n/a	-2070.2	-2589.1	18	no
Cobia1	18	2786606	2333302	n/a	0	n/a	-2443.4	-3141.7	18	no
Turrum7	18	2785594	2354766	n/a	0	n/a	-1676.6	-2286.1	18	no
Sunfish2	18	2784391	2368653	n/a	0	n/a	-1683.8	-1944.4	18	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
Turrum5	18	2780180	2356691	n/a	0	n/a	-1411.7	-1846.7	18	no
Kingfish9	18	2774207	2314644	n/a	0	n/a	-2314	-2987.9	18	no
Kingfish8	18	2766768	2319041	n/a	0	n/a	-2289.3	-3010.8	18	no
Snapper1	18	2763929	2362938	n/a	0	n/a	-1172.8	-1709	18	no
Snapper	18	2763929	2362938	n/a	0	n/a	-1172.8	-1709	18	no
WestMoonfish1	18	2760997	2368277	n/a	0	n/a	-1523.4	-1946.5	18	no
ZaneGrey1	18	2760502	2321223	n/a	0	n/a	-2297.7	-2989.3	18	no
Bream1	18	2743954	2327976	n/a	0	n/a	-1878.8	-2595.4	18	no
Omeo	18	2736696	2317734	n/a	0	n/a	-2280.9	-2512.5	18	no
Seahorse1	18	2734125	2364019	n/a	0	n/a	-1406	-1453.3	18	no
Barracouta3	18	2728797	2350406	n/a	0	n/a	-1001.5	-1463.7	18	no
Bullseye	18	2723620	2320362	n/a	0	n/a	-2100.8	-2267	18	no
WestWhiptail1	18	2719026	2350092	n/a	0	n/a	-1172.4	-1229.2	18	no
Blenny1	18	2710713	2333805	n/a	0	n/a	-1243.7	-1592.6	18	no
Dolphin1	18	2707487	2332052	n/a	0	n/a	-1242.1	-1650.7	18	no
Pearch2	18	2703421	2323090	n/a	0	n/a	-1161.1	-1273.7	18	no
Kyarra1A	18	2690428	2311385	n/a	0	n/a	-964.2	-1010.9	18	no
TommyRuff1	18	2686766	2319025	n/a	0	n/a	-952.69	-1114.6	18	no
Drummer1	18	2783672	2331495	n/a	0	n/a	-2460.2	-3137.7	18	no
Fortescue3	18	2785434	2340855	n/a	0	n/a	-2407.3	-3210	18	no
Barracouta5	18	2732789	2352535	n/a	0	n/a	-1052.7	-1485.1	18	no
Barracouta4	18	2737315	2355029	n/a	0	n/a	-1097.6	-1508.5	18	no
Whiptail1A	18	2720415	2350188	n/a	0	n/a	-1149.7	-1206.1	18	no
Tarwhine1	18	2720950	2341321	n/a	0	n/a	-1418.5	-1826.4	18	no
Seahorse2	18	2728764	2363182	n/a	0	n/a	-1409.6	-1450.5	18	no
West Seahorse	18	2729819	2363297	n/a	0	n/a	-1414.9	-1457.3	18	no

Bore_ID	VAF Lay	Bore_x	Bore_y	Depth (m)	Surface (mAHD)	Depth (mAHD)	TopLay (mAHD)	BotLay (mAHD)	New Lay	Diff
Luderick1	18	2737252	2337069	n/a	0	n/a	-1826.8	-2499.2	18	no
Wirrah1	18	2746783	2364504	n/a	0	n/a	-1505.6	-2058.9	18	no
Wirrah2	18	2747519	2365142	n/a	0	n/a	-1491.9	-2021.7	18	no
Whiting1	18	2752555	2359104	n/a	0	n/a	-1265.5	-1880.2	18	no
Cod1	18	2760055	2345032	n/a	0	n/a	-2096.8	-2698.3	18	no
Snapper3	18	2761498	2361584	n/a	0	n/a	-1281.6	-1813.1	18	no
Snapper5	18	2761883	2360486	n/a	0	n/a	-1279.3	-1830.8	18	no
Veilfin1	18	2762314	2338728	n/a	0	n/a	-1939.3	-2519.7	18	no
Moonfish1	18	2763787	2368350	n/a	0	n/a	-1379.7	-1722.7	18	no
Moonfish2	18	2764969	2368408	n/a	0	n/a	-1332.3	-1683.9	18	no
West Kingfish	18	2770563	2318779	n/a	0	n/a	-2247.7	-2999.5	18	no
Turrum6	18	2777935	2358316	n/a	0	n/a	-1492.2	-1967.5	18	no
Remora1	18	2779805	2367419	n/a	0	n/a	-2187.9	-2447.5	18	no
Kingfish1	18	2779609	2318261	n/a	0	n/a	-2297.3	-3094.4	18	no
Sunfish1	18	2782979	2368800	n/a	0	n/a	-1752.3	-1997.1	18	no
Turrum1	18	2784149	2361923	n/a	0	n/a	-2069.4	-2462	18	no
Turrum2	18	2784501	2357221	n/a	0	n/a	-1538	-2039.1	18	no
Turrum3	18	2784501	2355320	n/a	0	n/a	-1579.7	-2174	18	no
Marlin4	18	2786130	2357629	n/a	0	n/a	-1838.3	-2359.6	18	no
Trumpeter 1	18	2792616	2338145	n/a	0	n/a	-2477.7	-3188.3	18	no

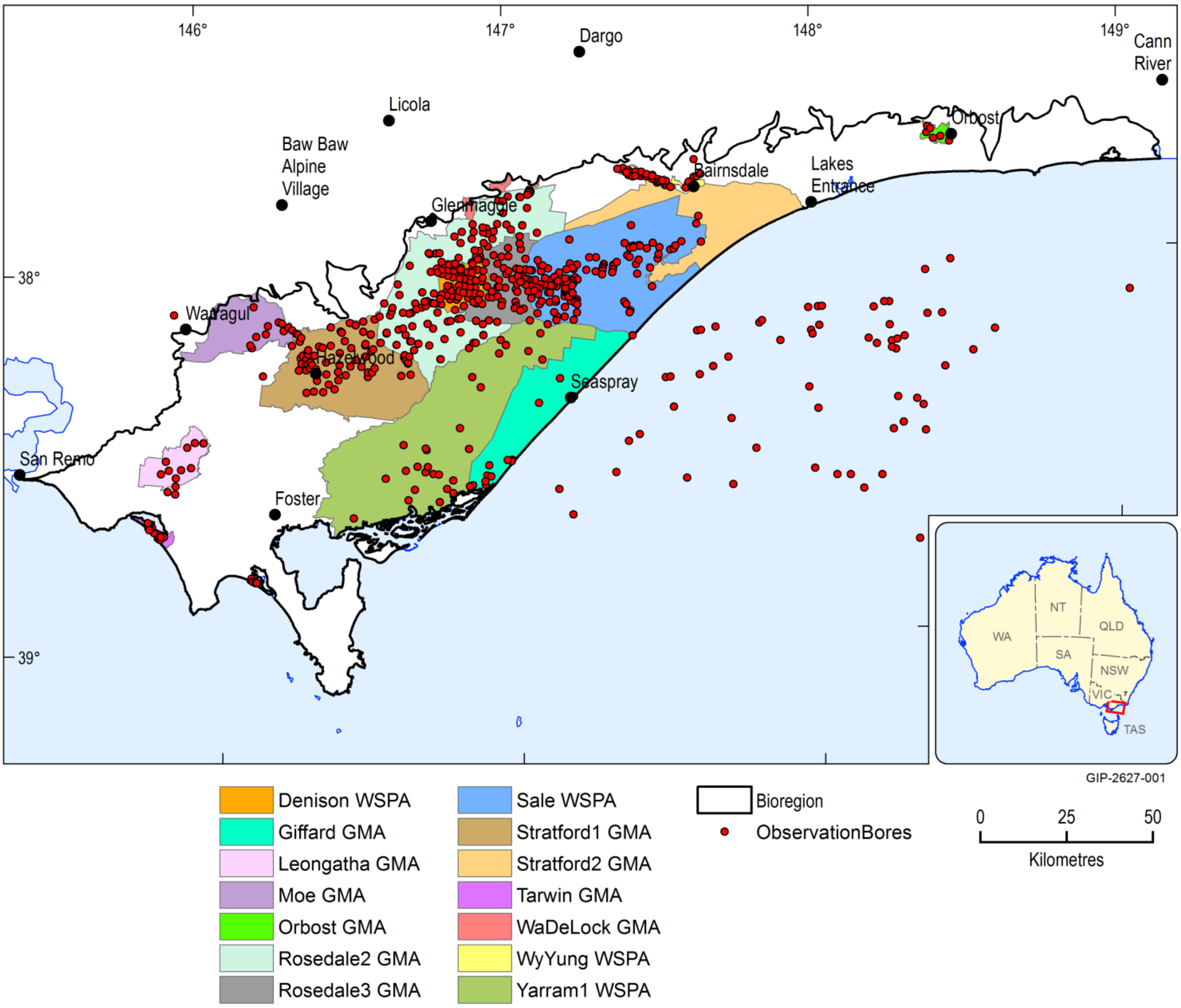


Figure 144 Location of observation bores used for model calibration

2.6.2.7.2 Baseflow estimates

Baseflow separation and analysis were conducted on all stream flow data within the study area to estimate the contribution of groundwater to streamflow. The estimated groundwater discharge volumes to streams were then used as a calibration flux target within ungauged catchments.

Baseflow separation was estimated using the approach developed by the USGS and subsequently implemented in the BFI software. Daily streamflow input data was sourced from the Victorian Water data warehouse (http://www.vicwaterdata.net/vicwaterdata/home) and extracted as computed daily flows. Periods with poor quality data and/or missing records were infilled to ensure a complete data record at each location. The program implements a digital filter procedure and combines a local minimums approach with a recession slope test. The program estimates the annual base-flow volume of unregulated rivers and streams and computes an annual base-flow index (BFI, the ratio of base flow to total flow volume for a given year) for multiple years of data at one or more gage sites. Although the method may not yield the true base flow as might be determined by a more sophisticated analysis, the index has been found to be consistent and indicative of base flow, and thus may be useful for analysis of long term base-flow trends (Arnold et al., 2010).

As a comparison, the derived BFI estimates were compared to independent values based on the Lyne and Hollick digital filter method (SKM, 2012) and recent GHD's study (GHD, 2013). The comparative values adopted a single consistent baseflow filter parameter of 0.98 applied to all sites thereby allowing a comparison from site to site on an equivalent basis.

2.6.2.7.3 Model calibration procedure

The calibration procedure included both a manual approach and application of parameter estimation procedures. Initial model calibration was made by using a manual trial-and-error approach. Due to the large number of solution points and the large number of model layers, it was found to be inefficient and difficult to make notable enhancements in the calibration process. As a result, automated calibration methods were adopted.

The automated calibration approach utilised three independent parameter estimation software packages, namely:

1. BeoPest implemented in Groundwater Vistas
2. DOS version of PEST (Doherty, 2010)
3. A simplex optimisation approach.

The same calibration targets were used by each package to enable a comparison of results.

The automated calibration procedure adopted a zonal approach. The zone calibration approach was based on a series of parameter zones in which the horizontal and vertical hydraulic conductivities were modified in order to minimise the variation between observed data and modelled prediction. A total of 36 zones based on geological extents and attributes were mapped as shown in Figure 145 to Figure 174.

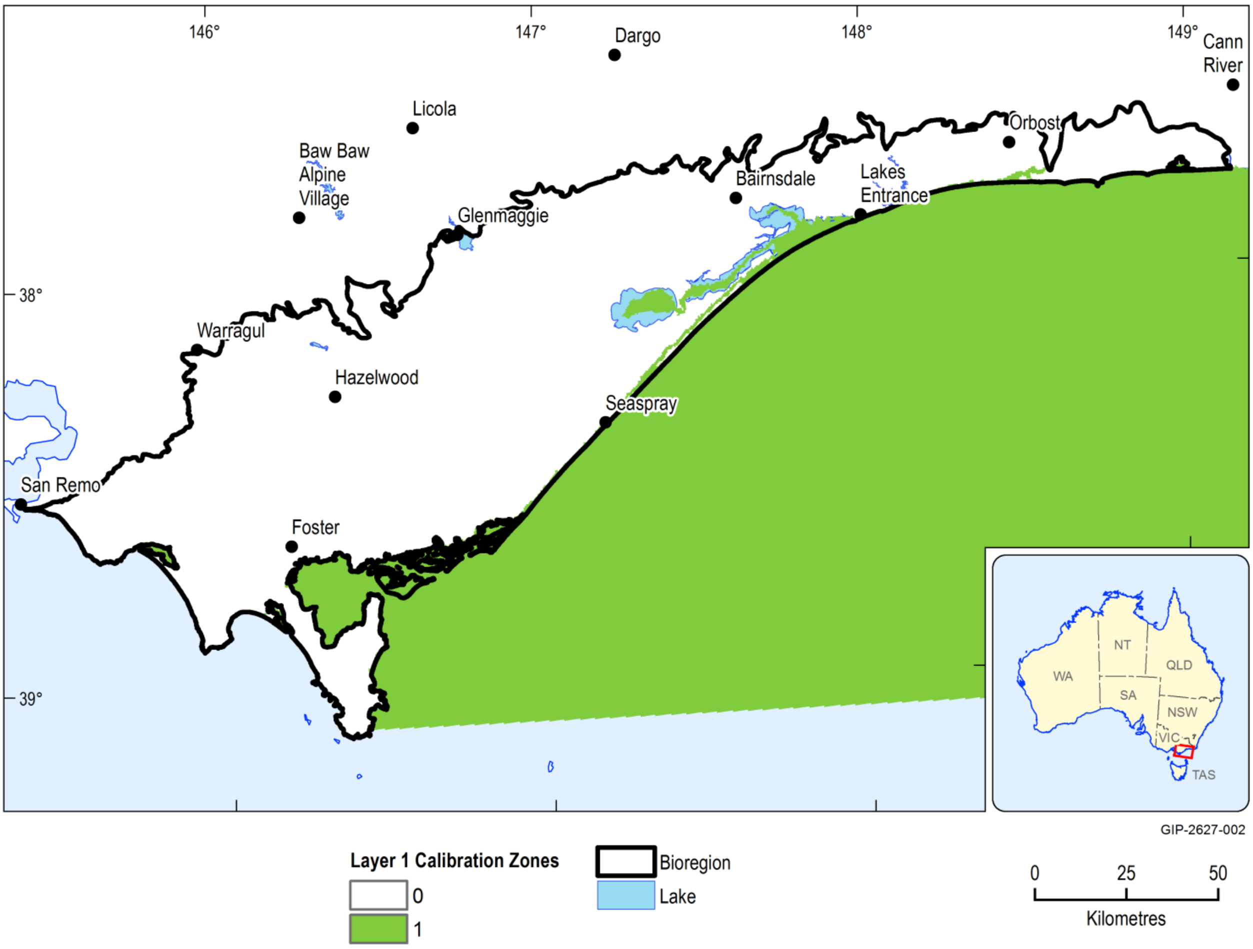


Figure 145 Spatial extent of zones used to calibrate modelled layer 1

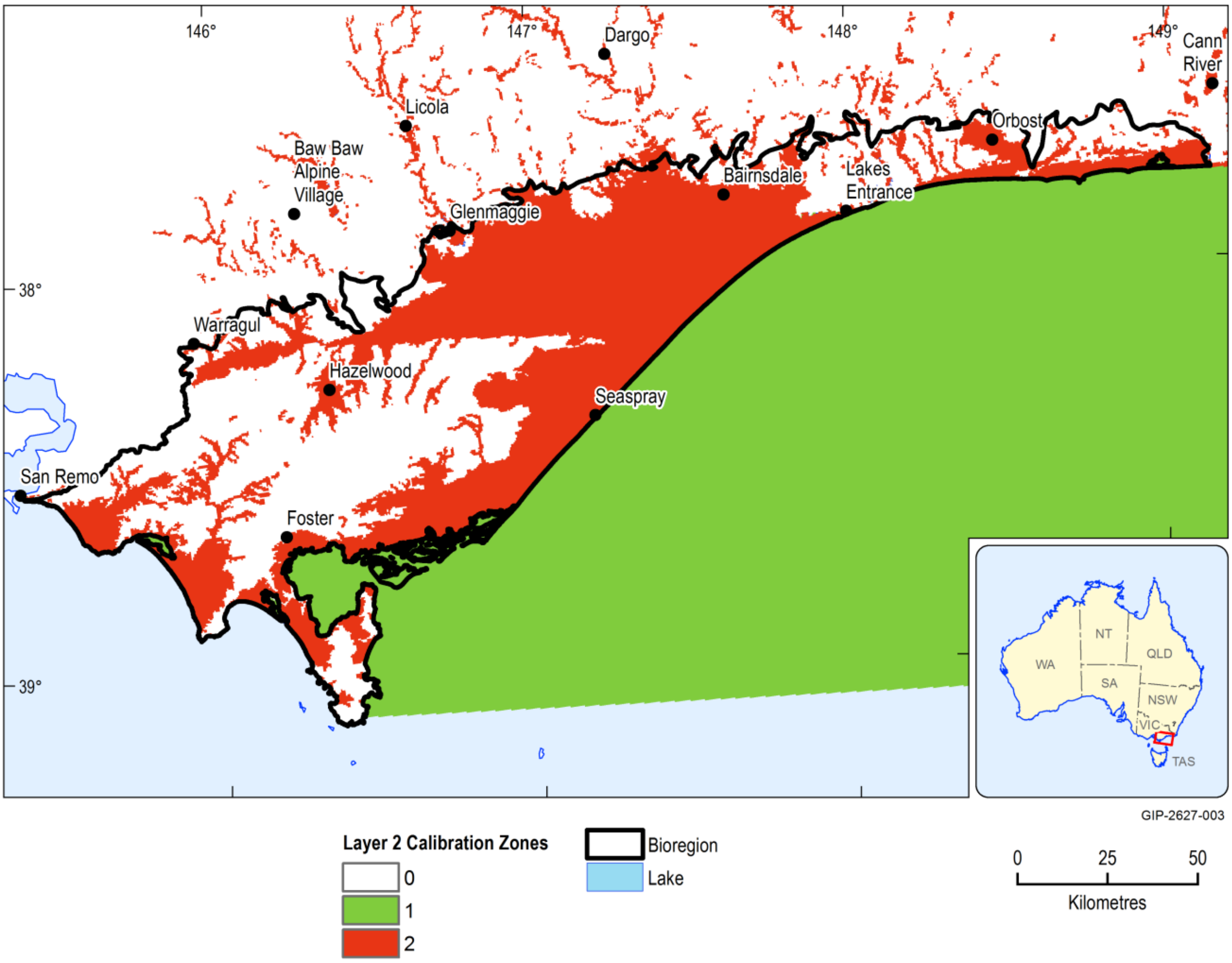


Figure 146 Spatial extent of zones used to calibrate modelled layer 2

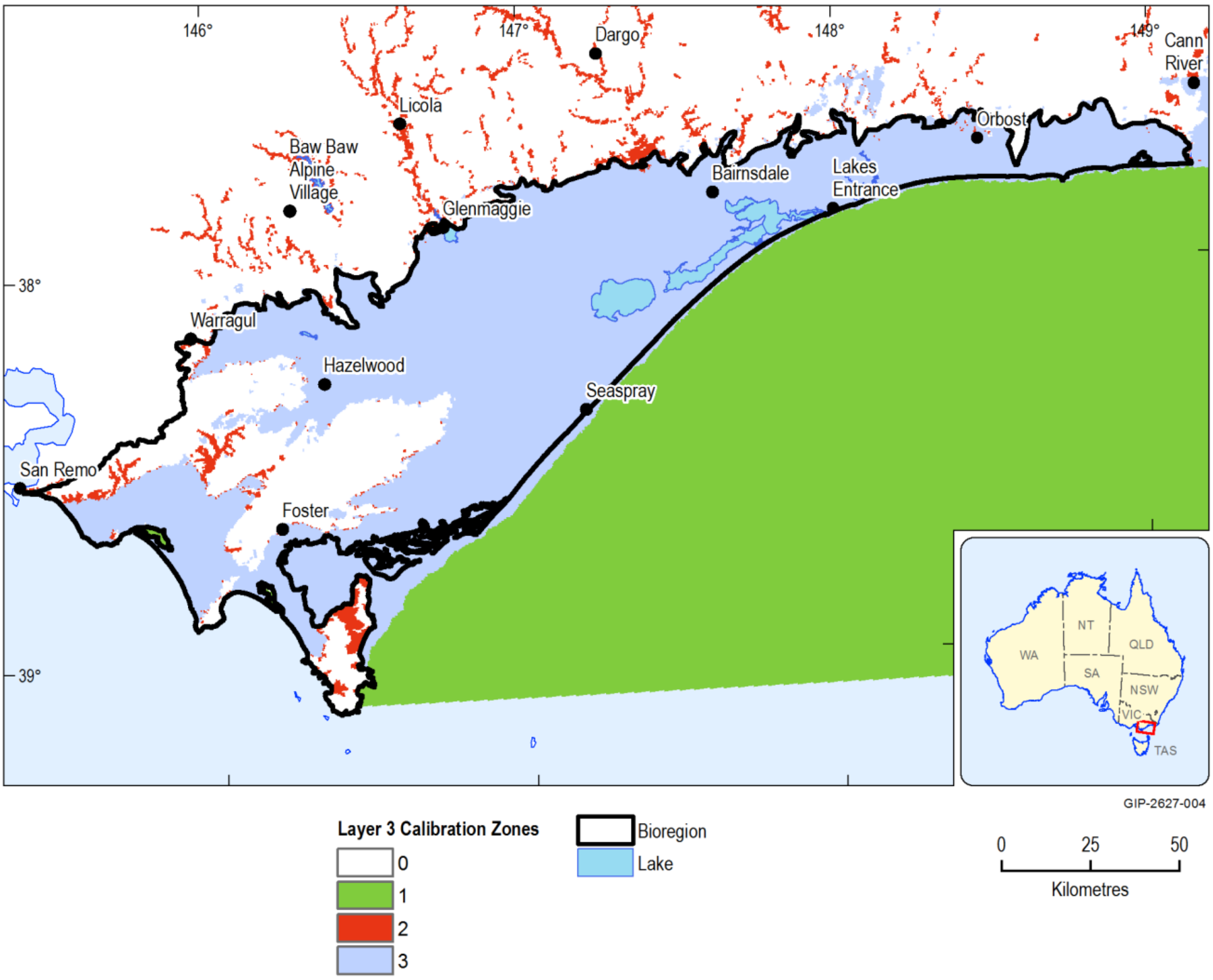


Figure 147 Spatial extent of zones used to calibrate modelled layer 3

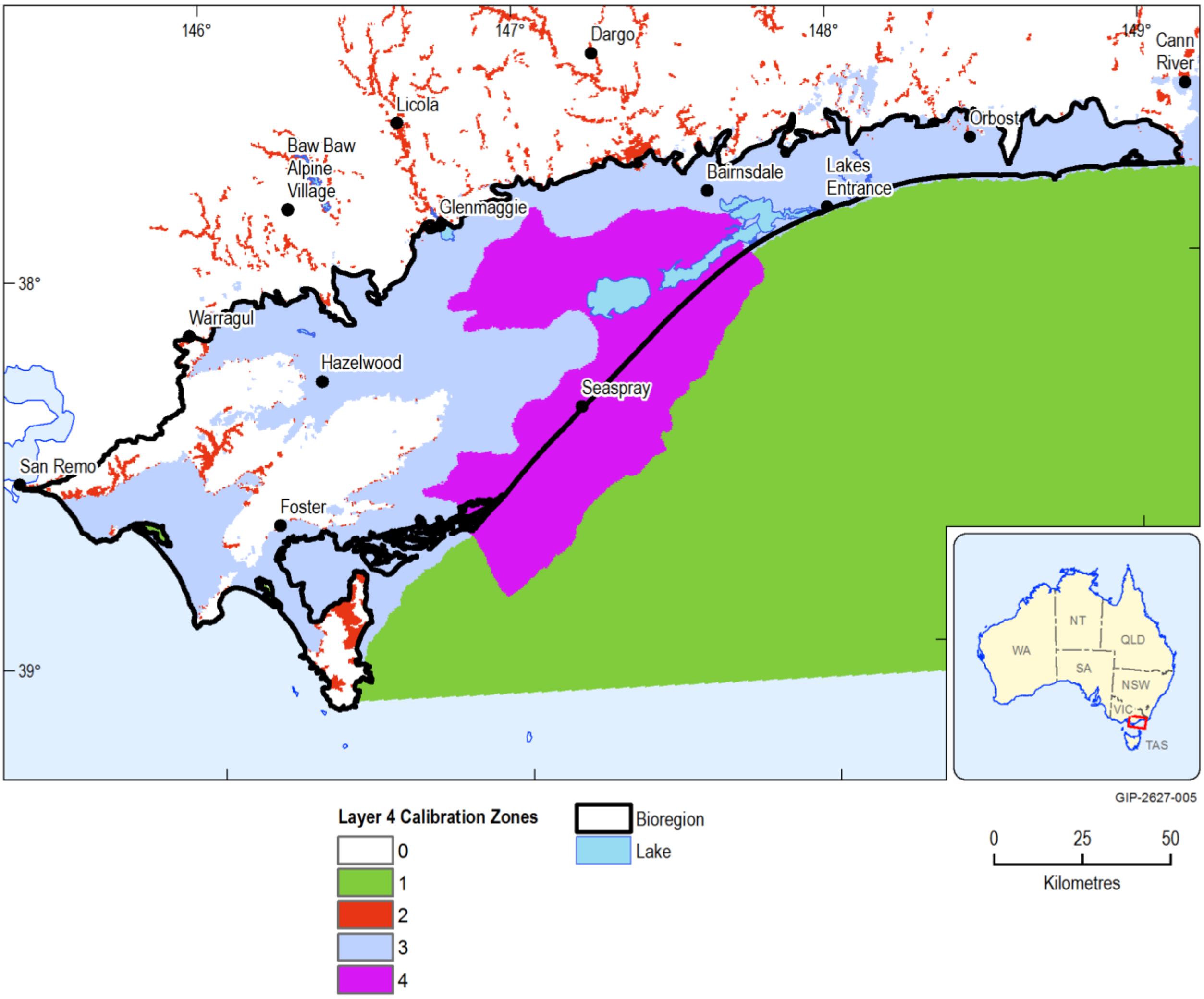


Figure 148 Spatial extent of zones used to calibrate modelled layer 4

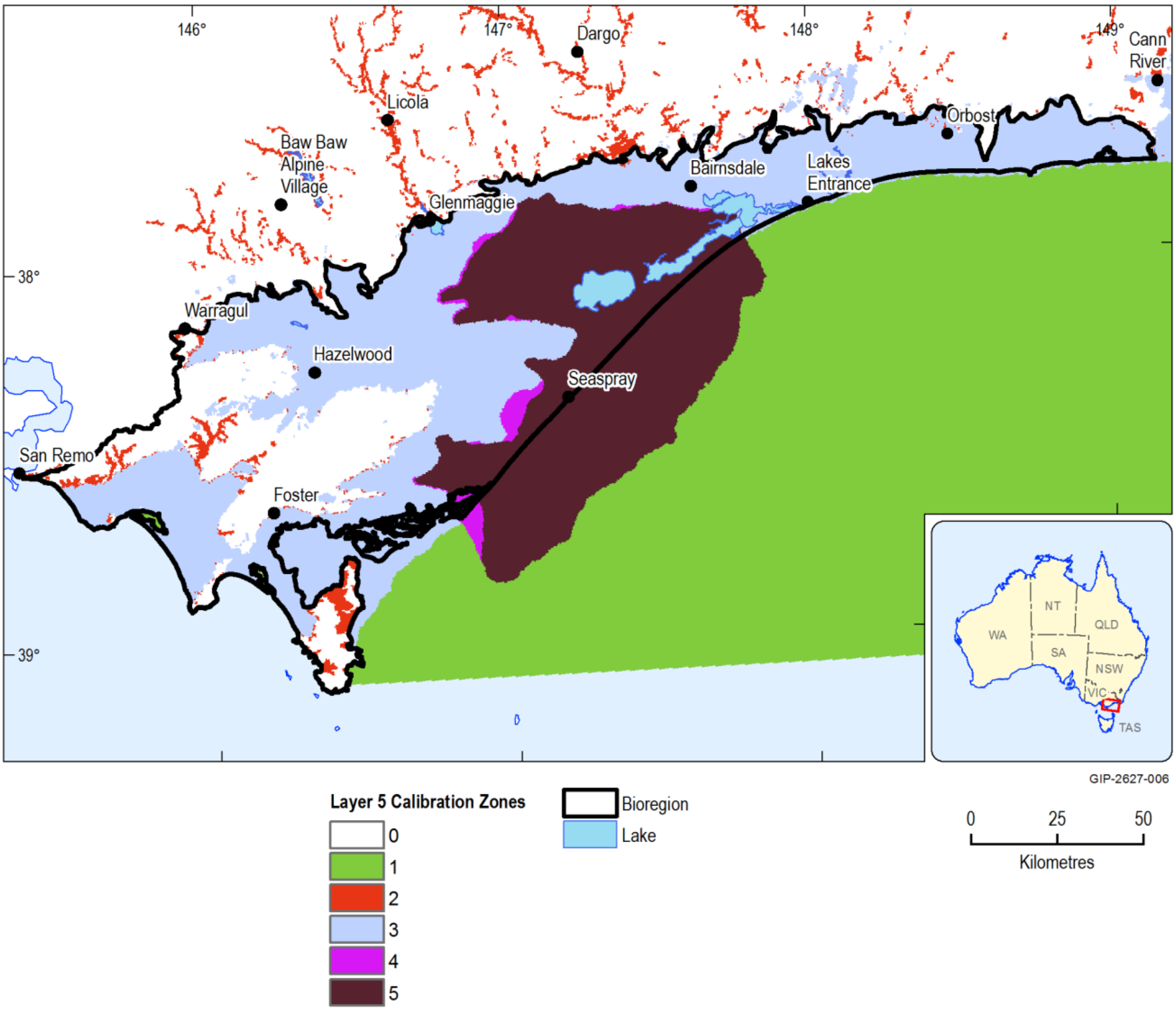


Figure 149 Spatial extent of zones used to calibrate modelled layer 5

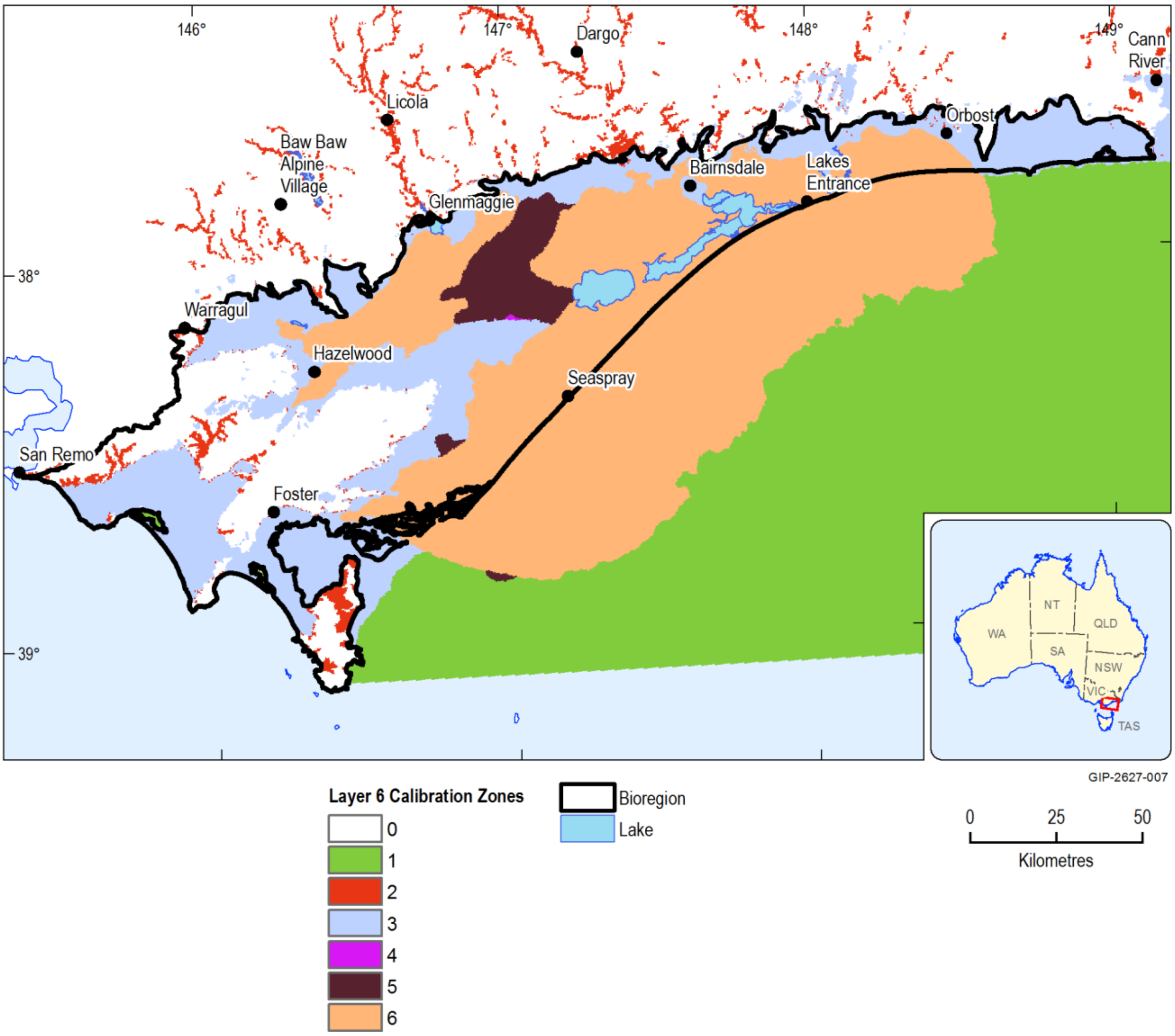


Figure 150 Spatial extent of zones used to calibrate modelled layer 6

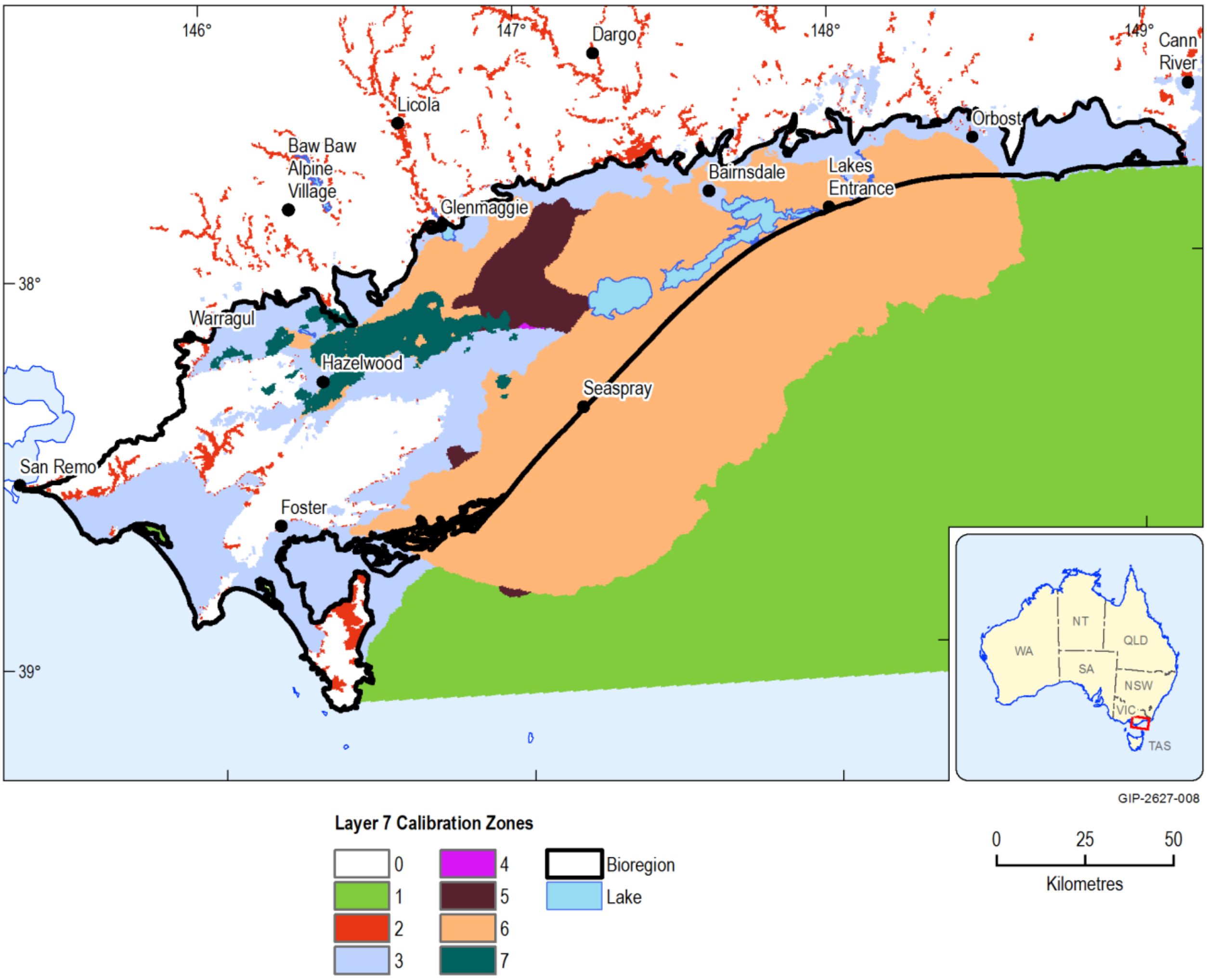


Figure 151 Spatial extent of zones used to calibrate modelled layer 7

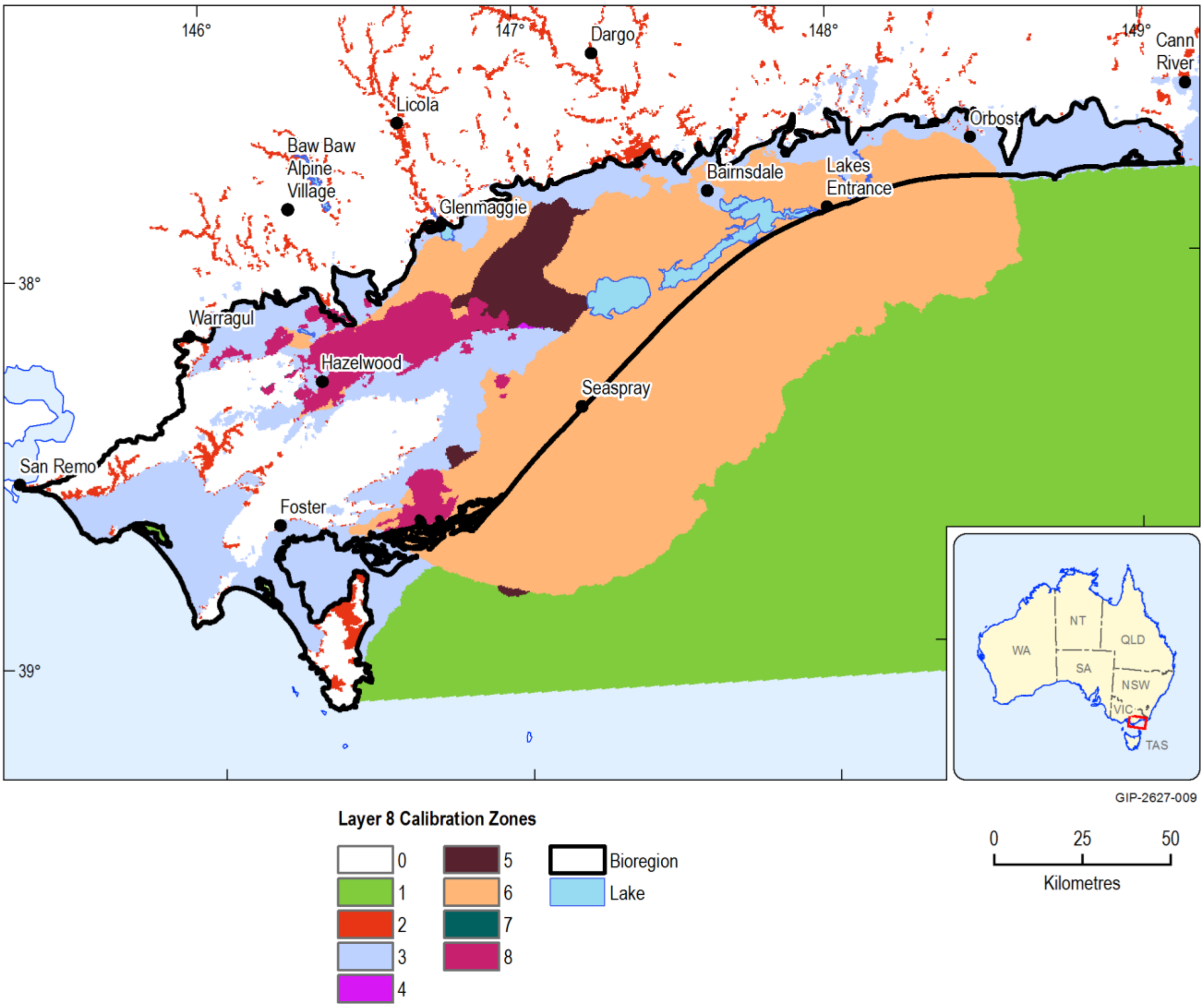


Figure 152 Spatial extent of zones used to calibrate modelled layer 8

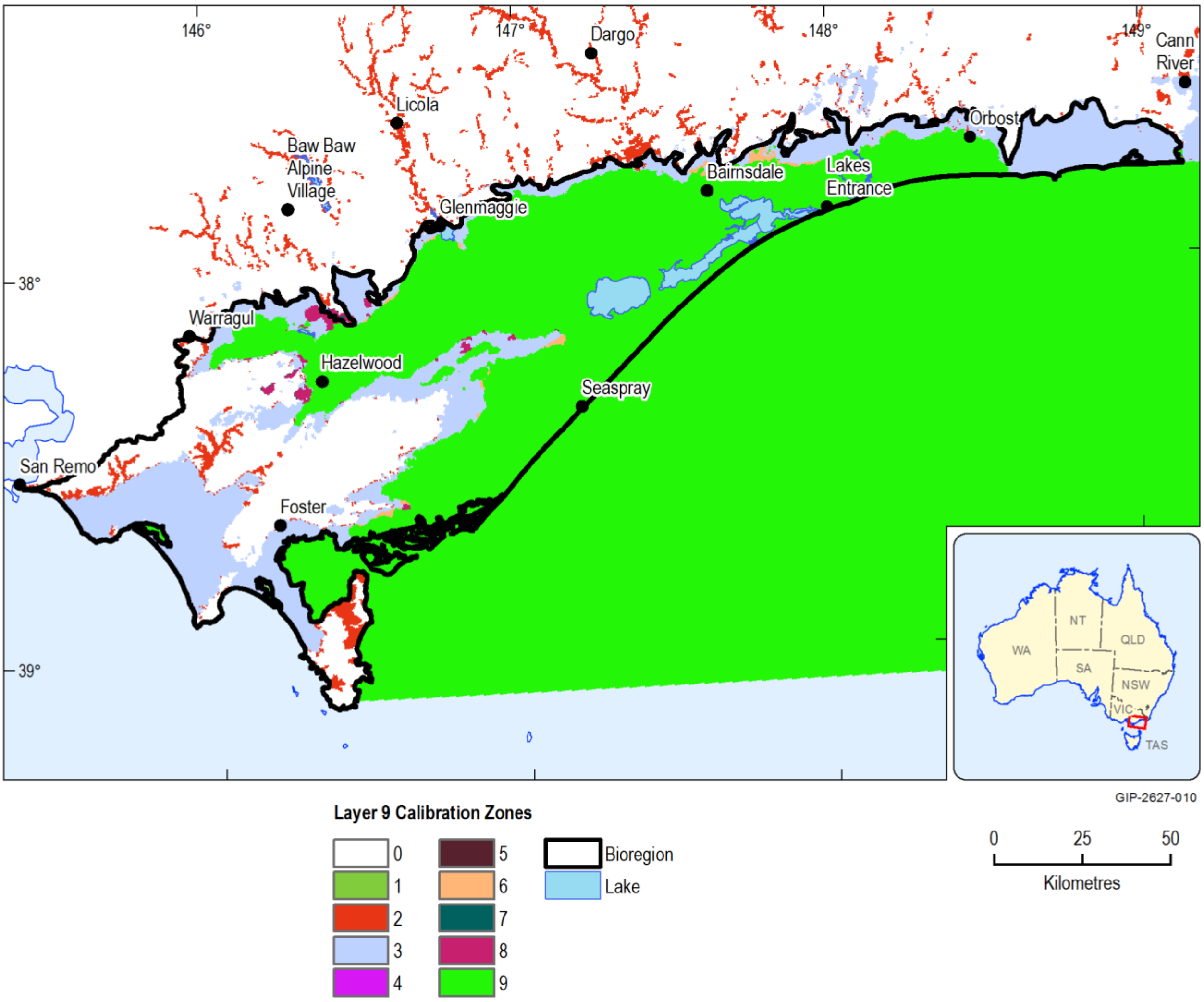


Figure 153 Spatial extent of zones used to calibrate modelled layer 9

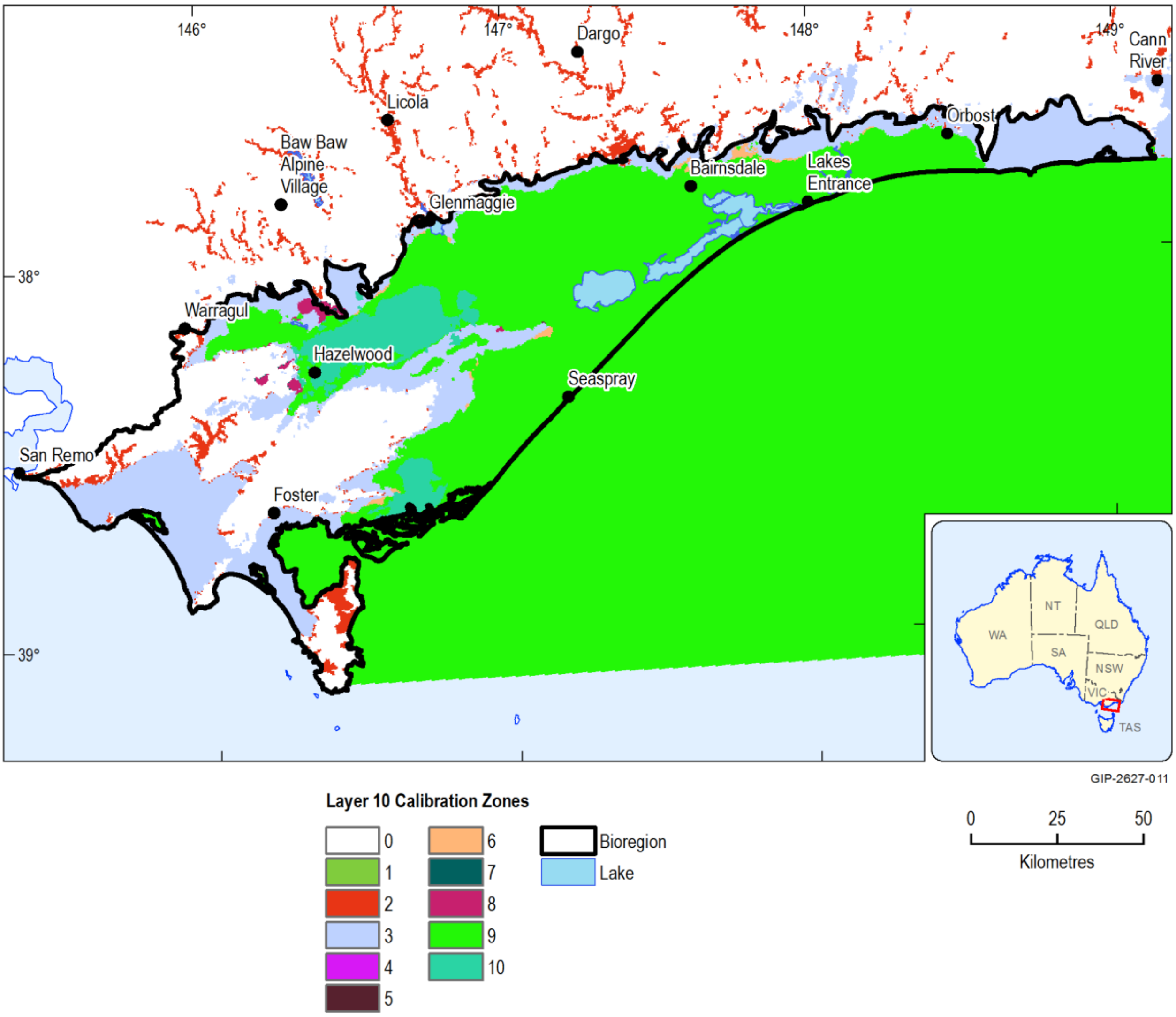


Figure 154 Spatial extent of zones used to calibrate modelled layer 10

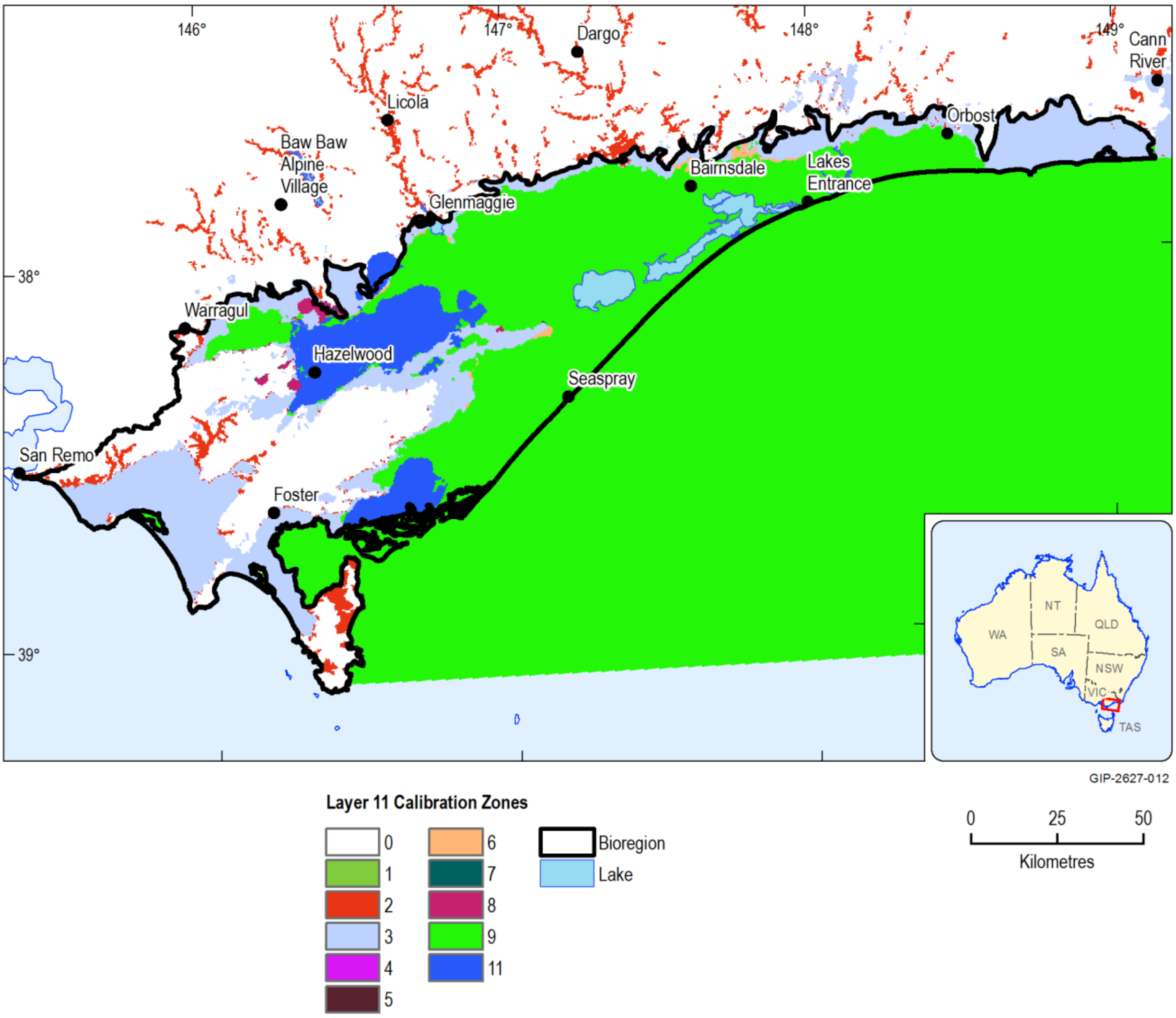


Figure 155 Spatial extent of zones used to calibrate modelled layer 11

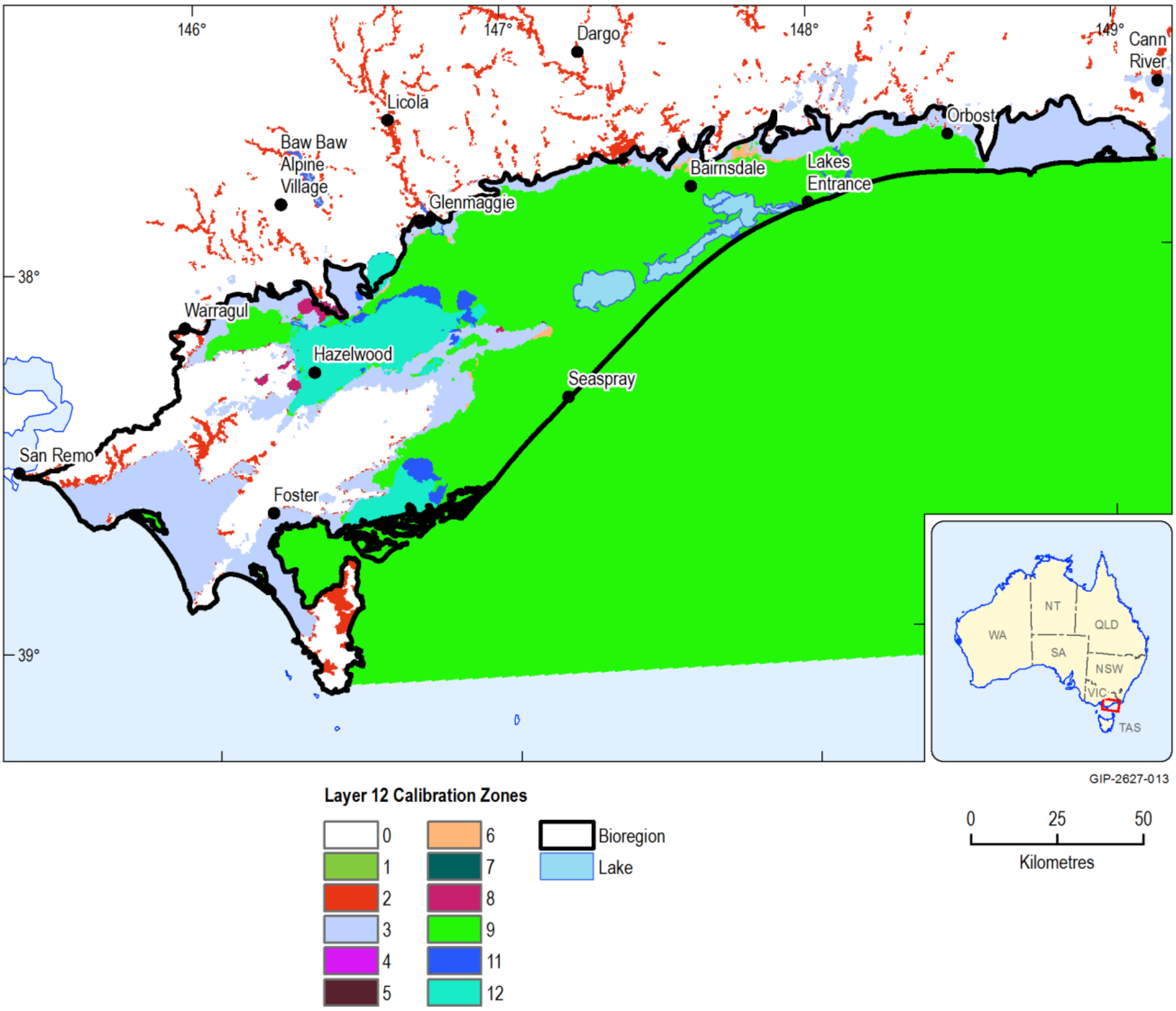


Figure 156 Spatial extent of zones used to calibrate modelled layer 12

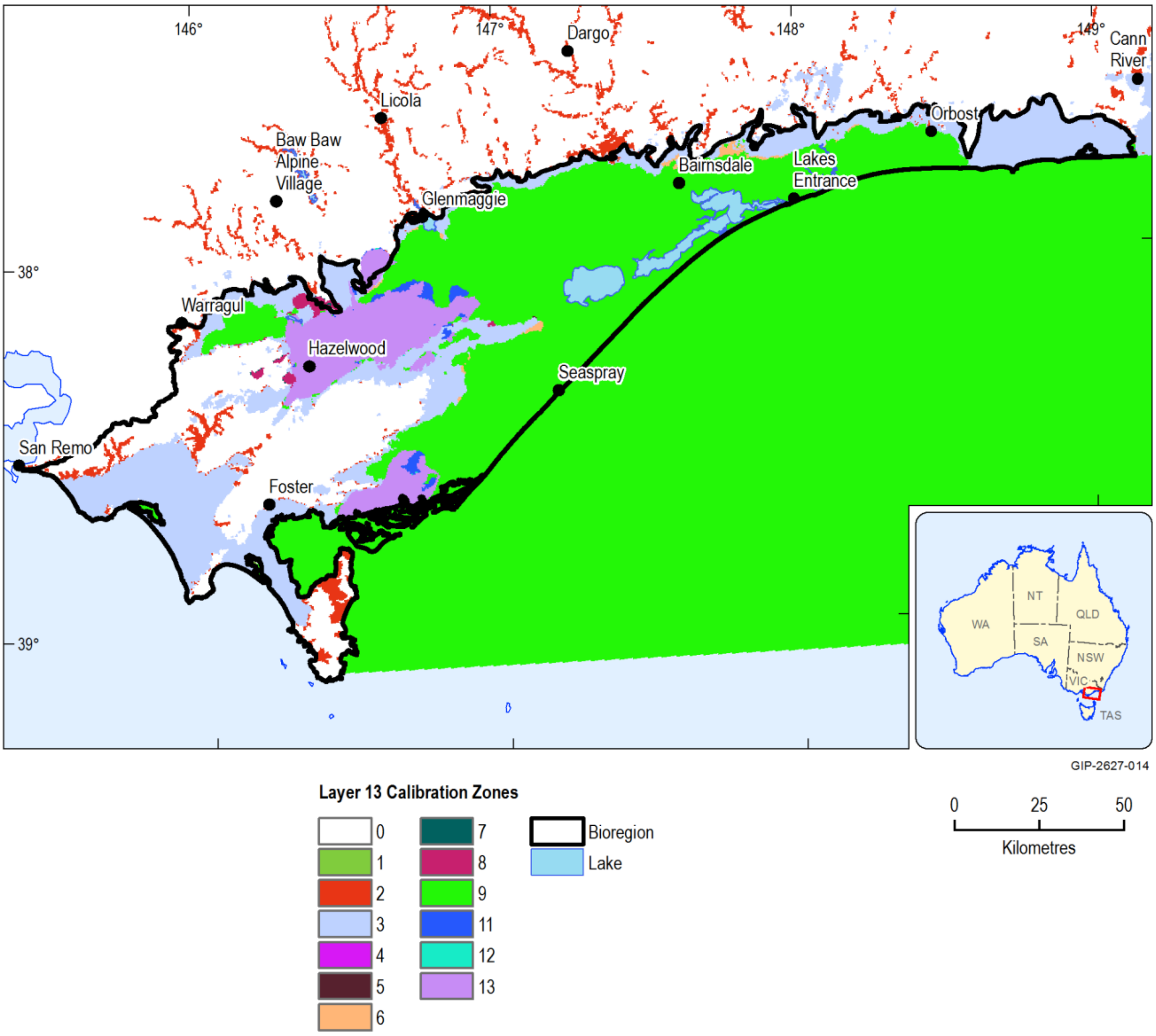


Figure 157 Spatial extent of zones used to calibrate modelled layer 13

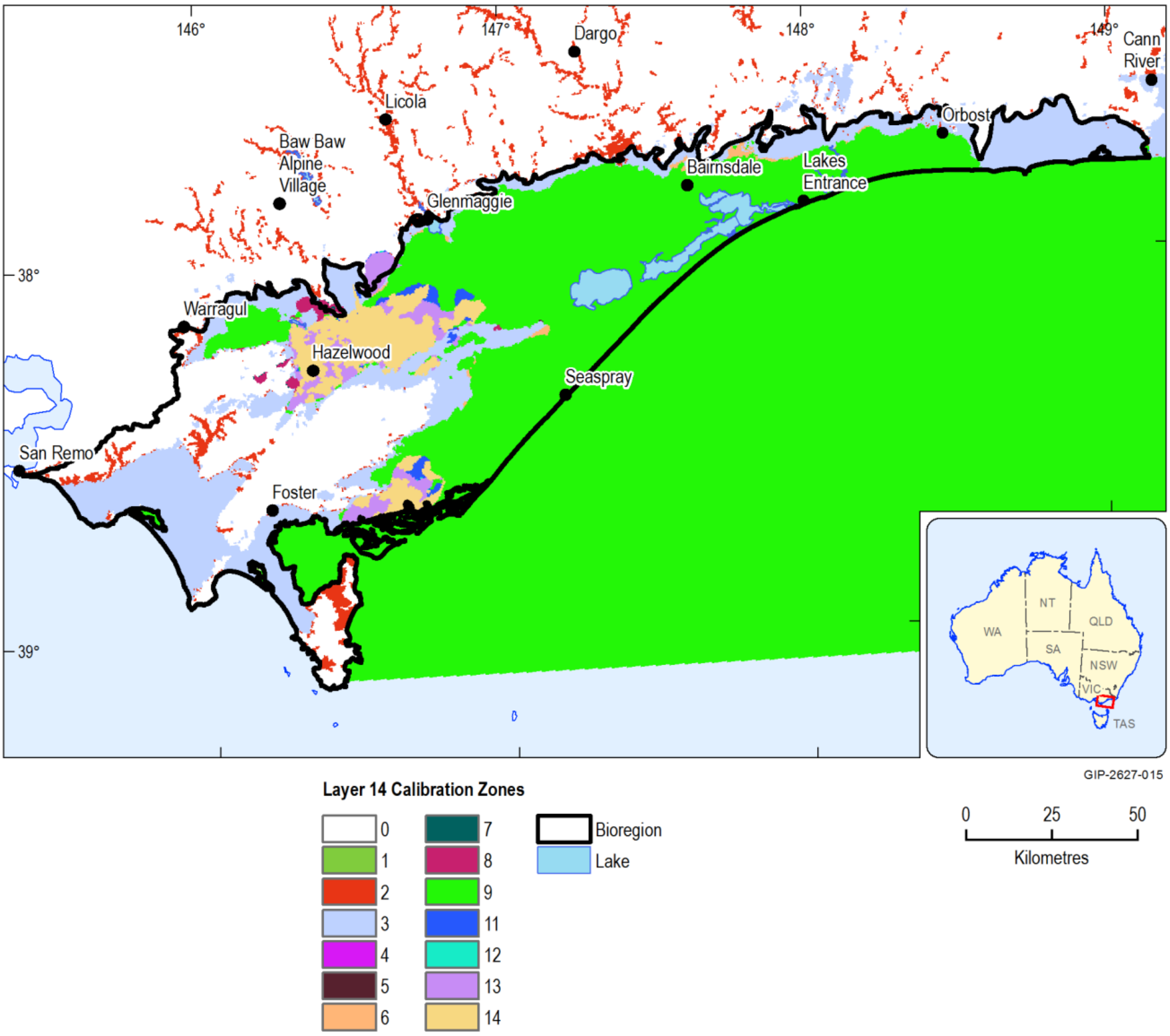


Figure 158 Spatial extent of zones used to calibrate modelled layer 14

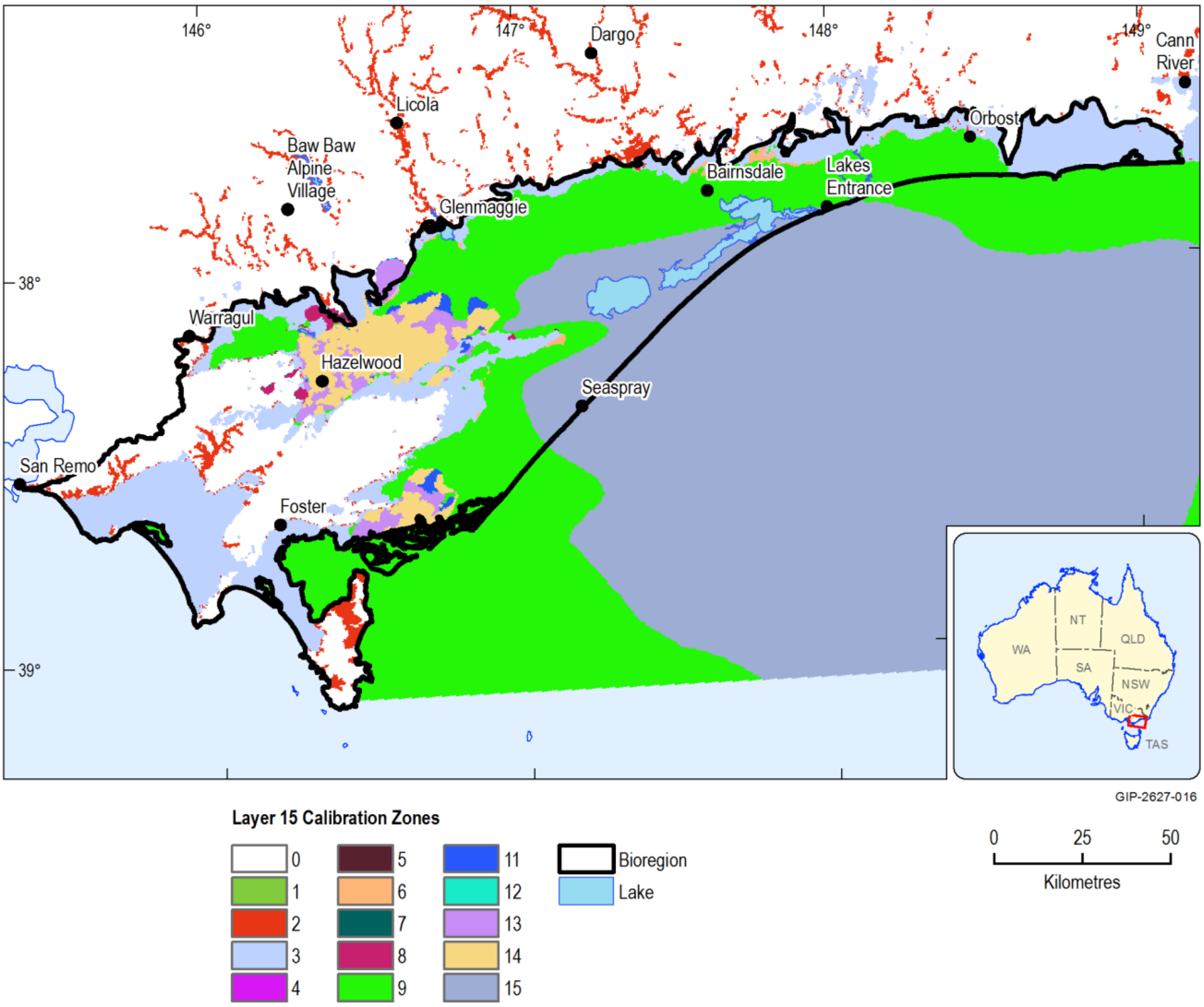


Figure 159 Spatial extent of zones used to calibrate modelled layer 15

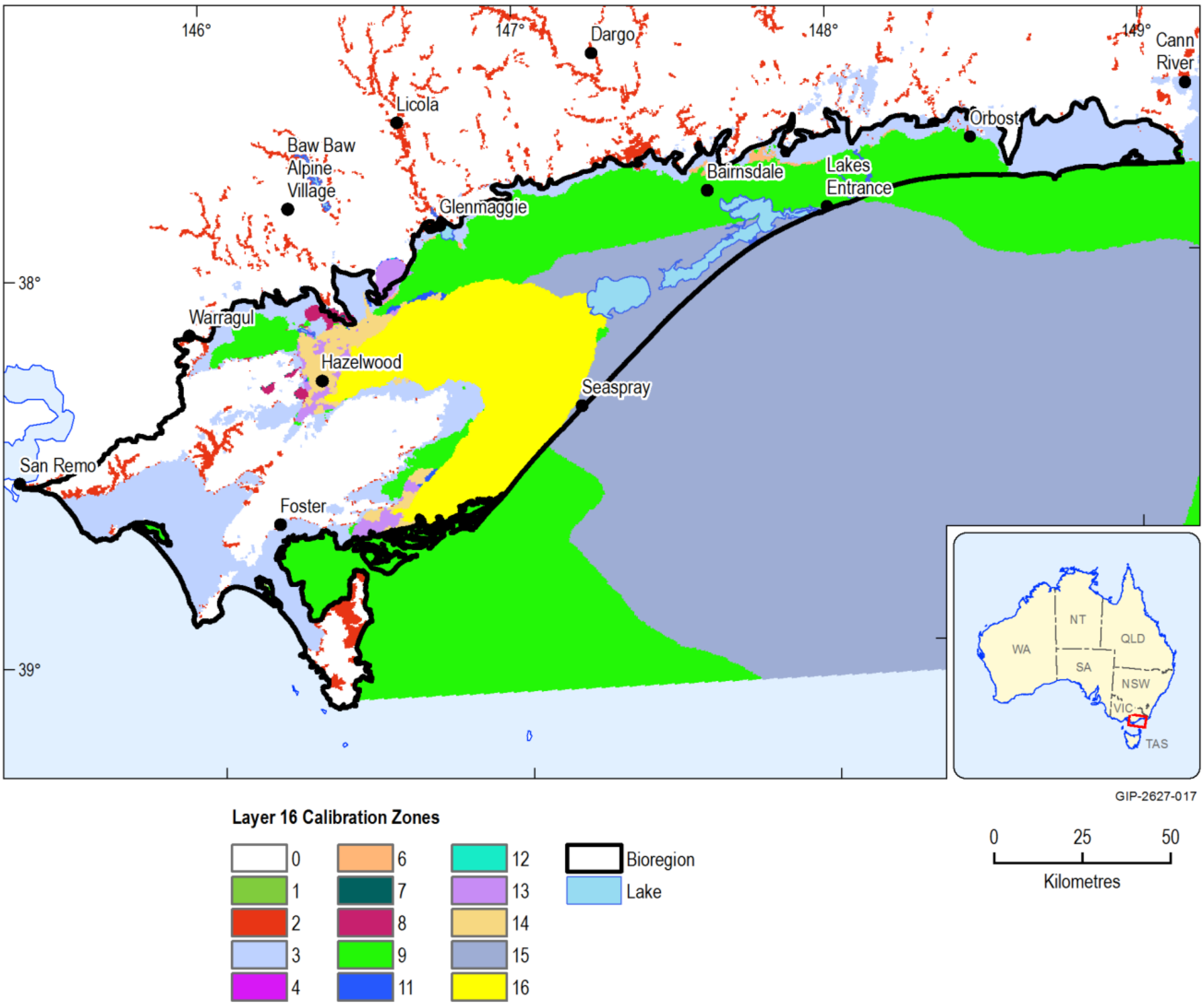


Figure 160 Spatial extent of zones used to calibrate modelled layer 16

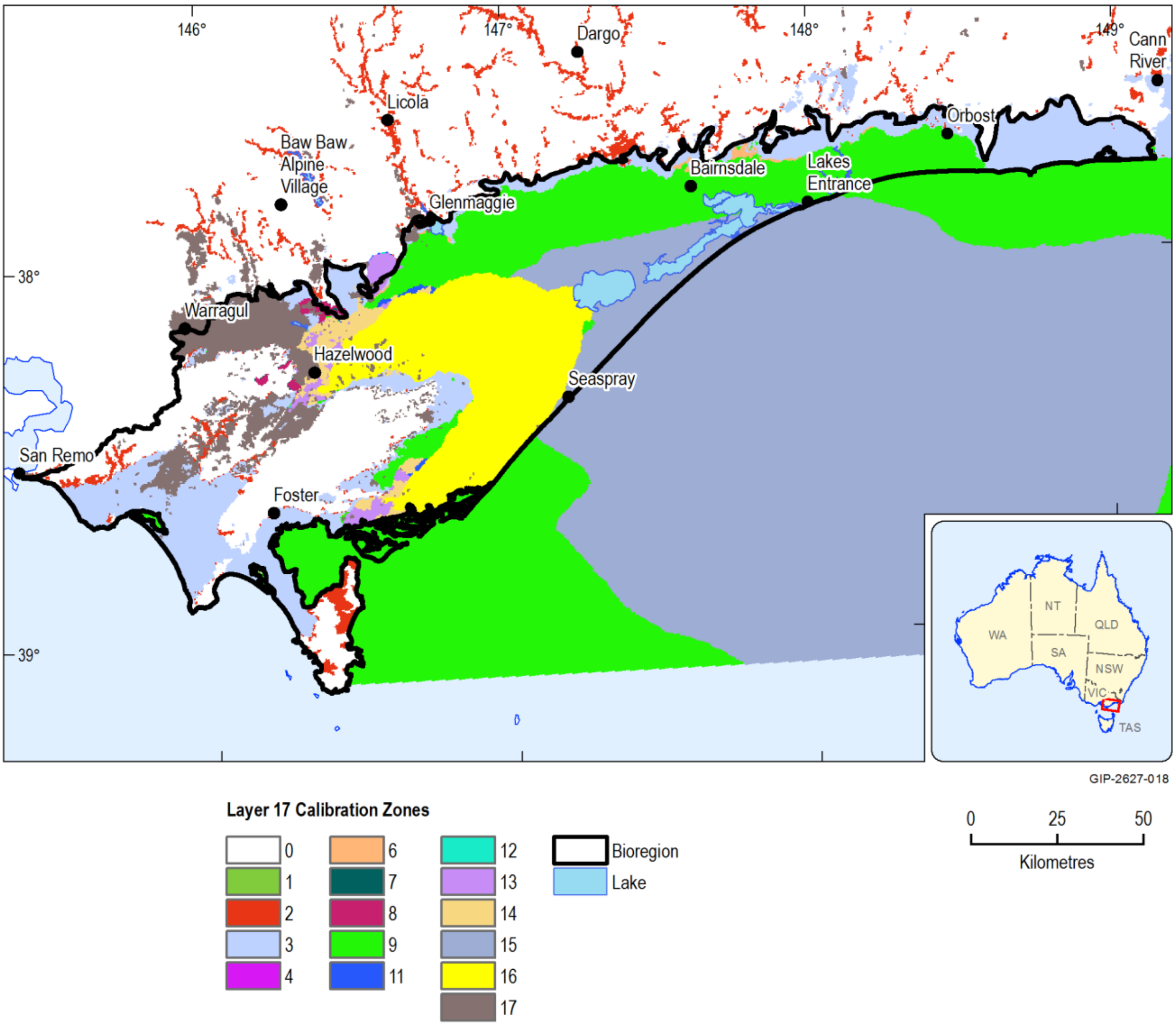


Figure 161 Spatial extent of zones used to calibrate modelled layer 17

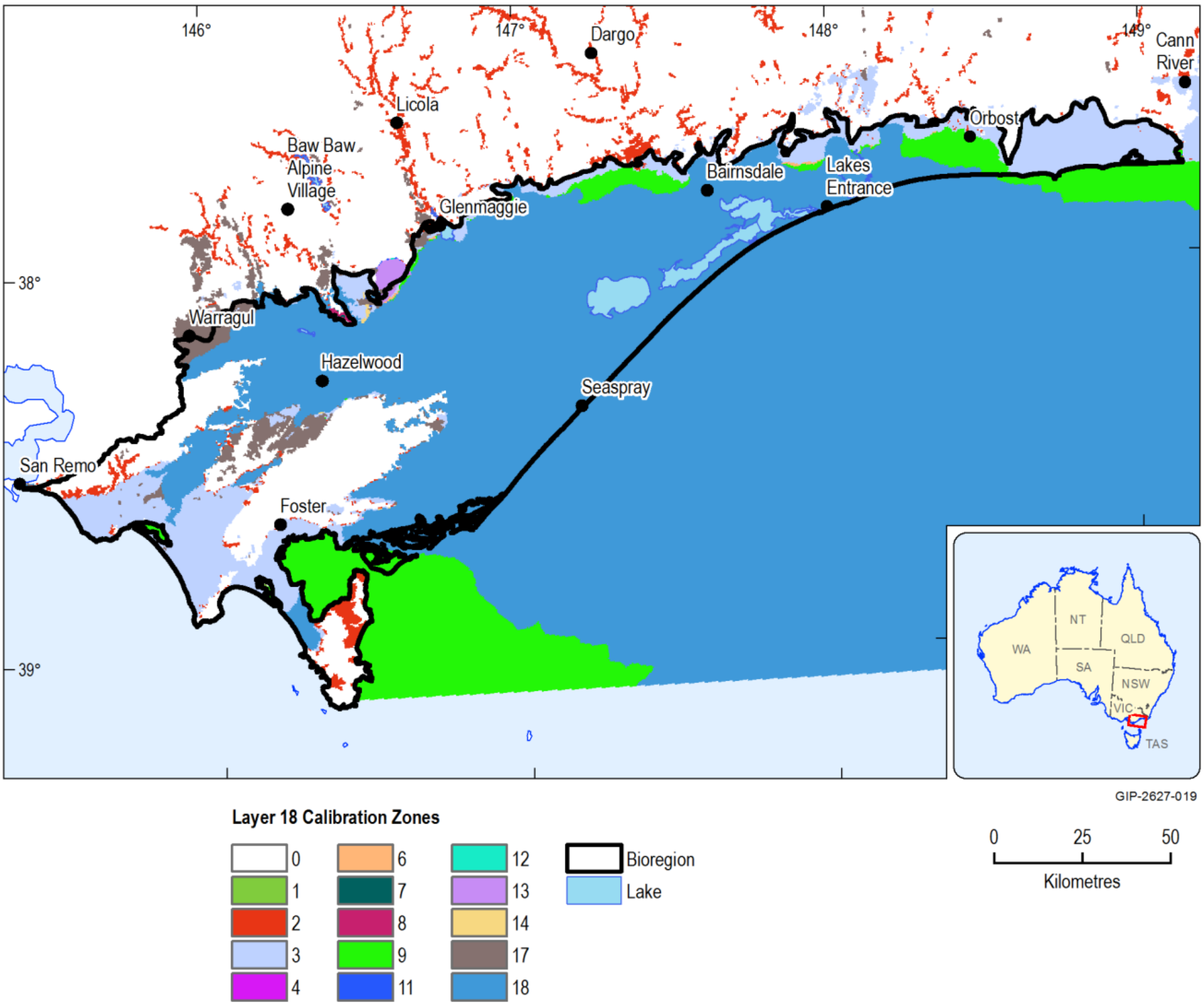


Figure 162 Spatial extent of zones used to calibrate modelled layer 18

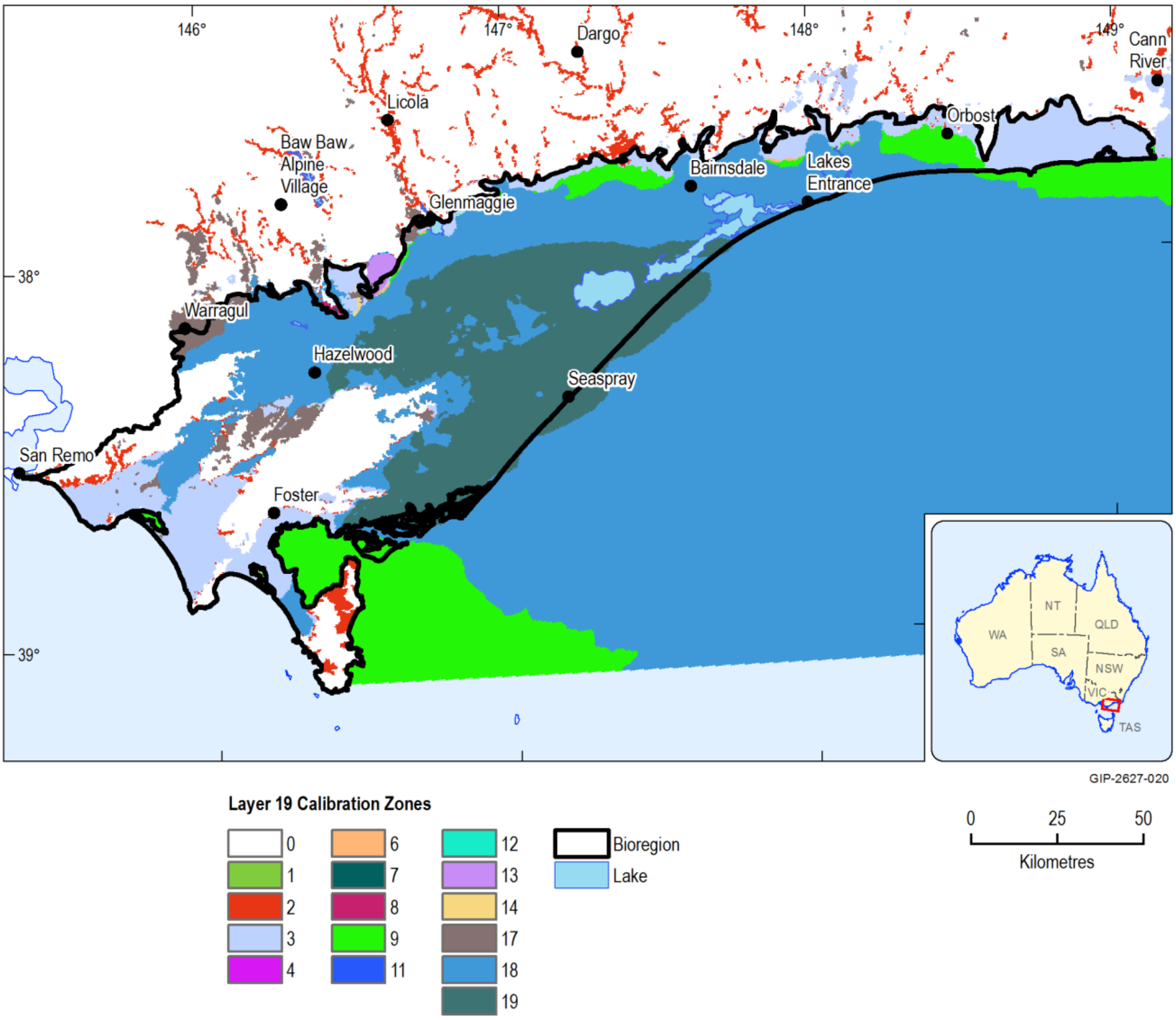


Figure 163 Spatial extent of zones used to calibrate modelled layer 19

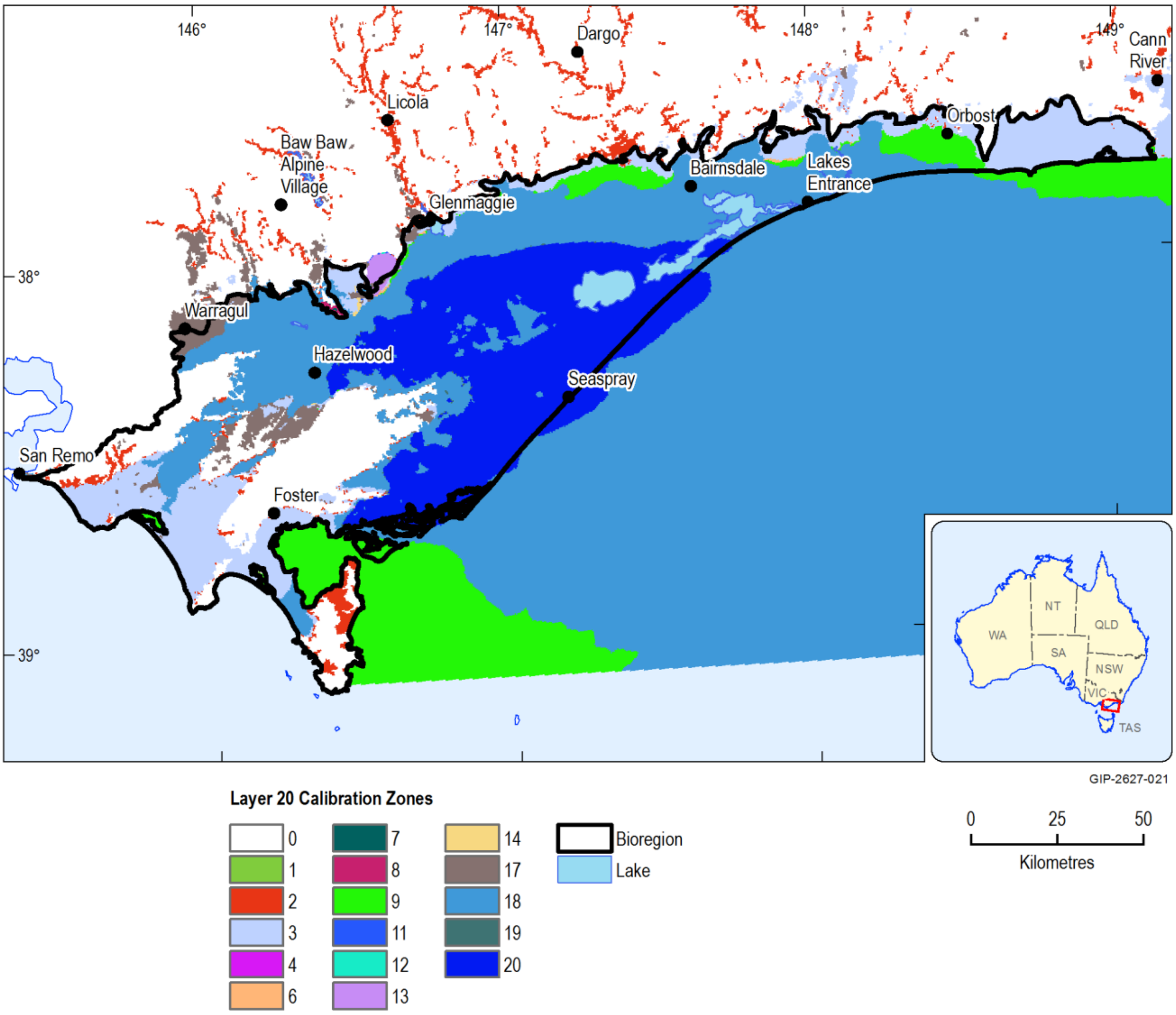


Figure 164 Spatial extent of zones used to calibrate modelled layer 20

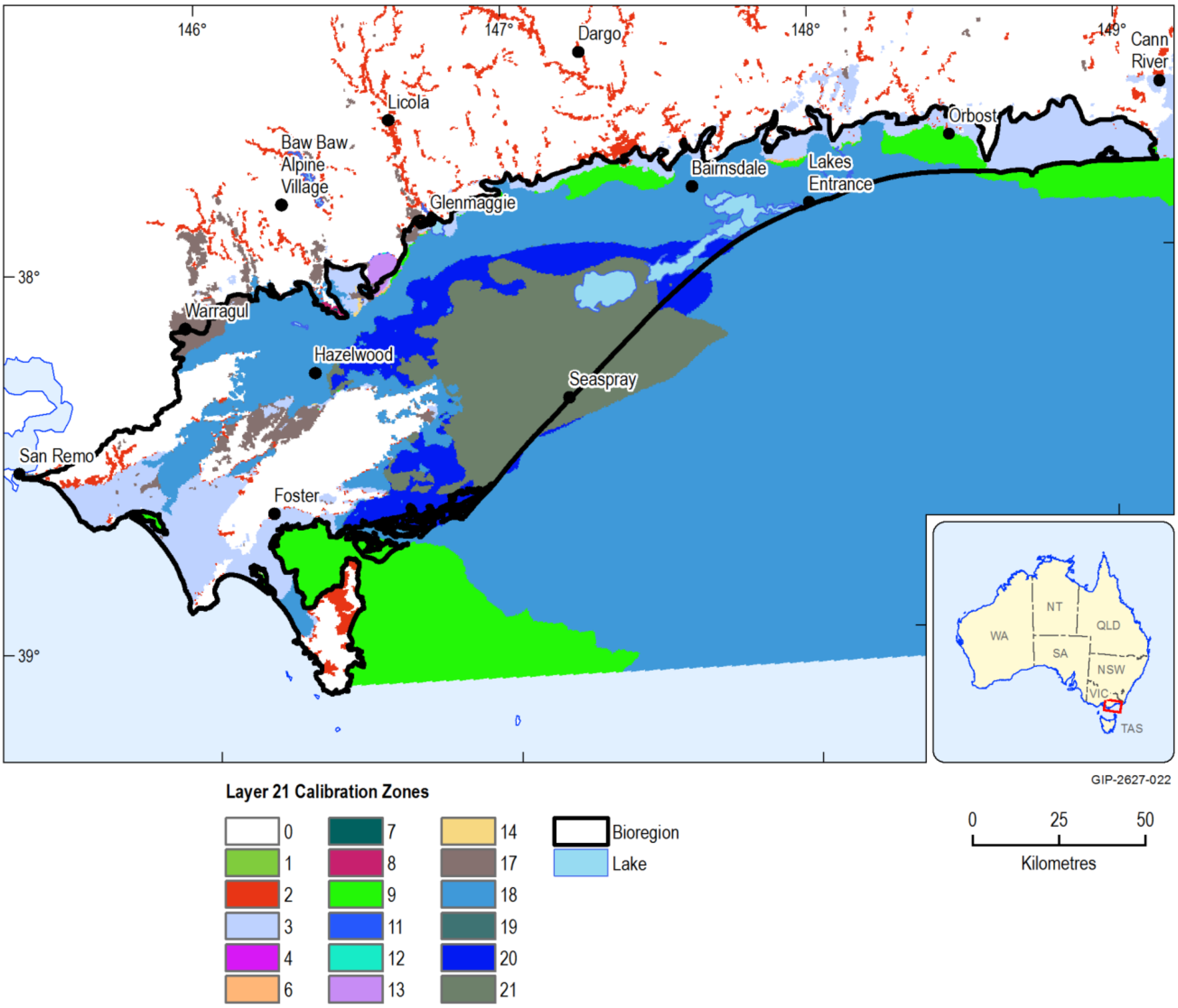


Figure 165 Spatial extent of zones used to calibrate modelled layer 21

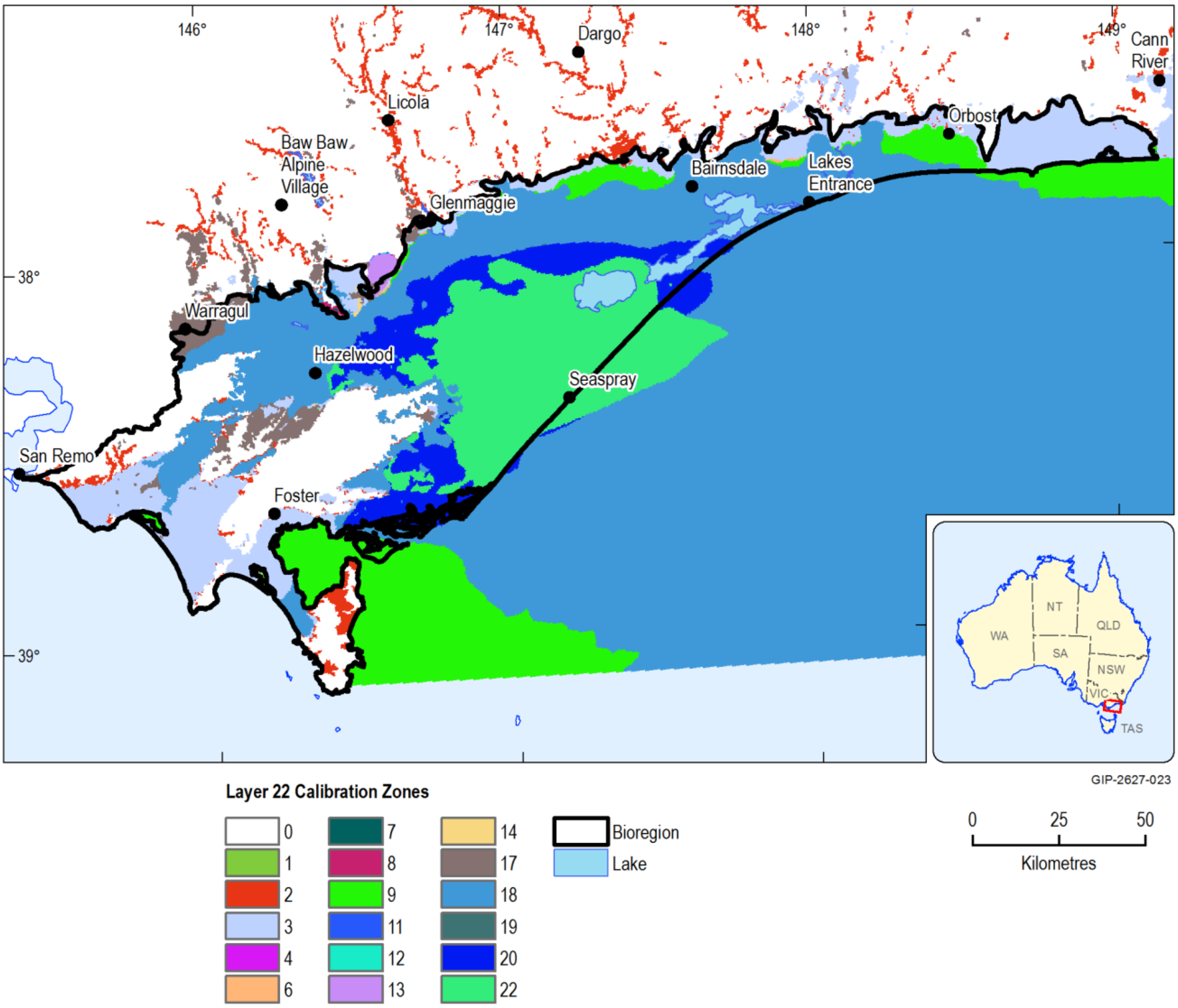


Figure 166 Spatial extent of zones used to calibrate modelled layer 22

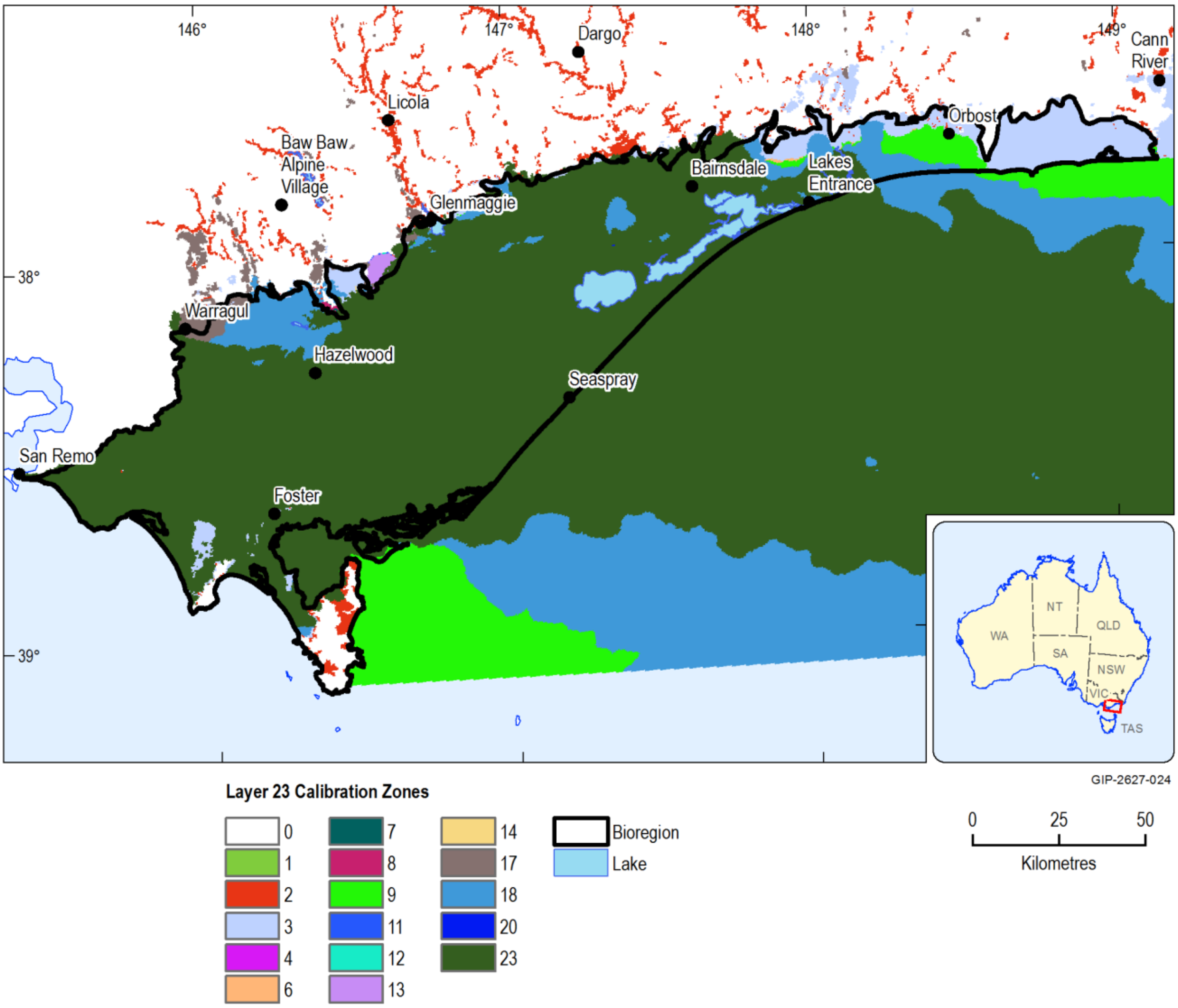


Figure 167 Spatial extent of zones used to calibrate modelled layer 23

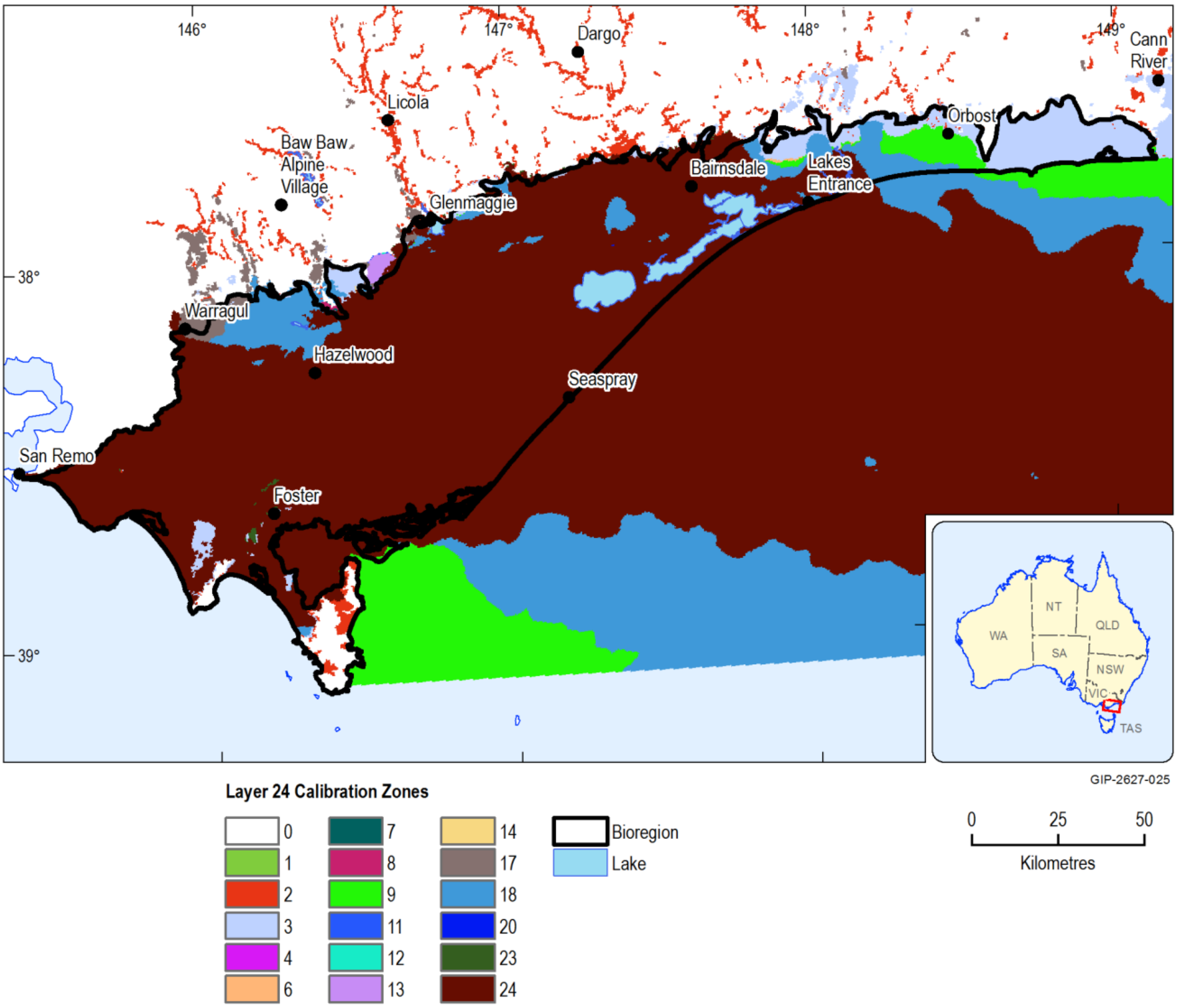


Figure 168 Spatial extent of zones used to calibrate modelled layer 24

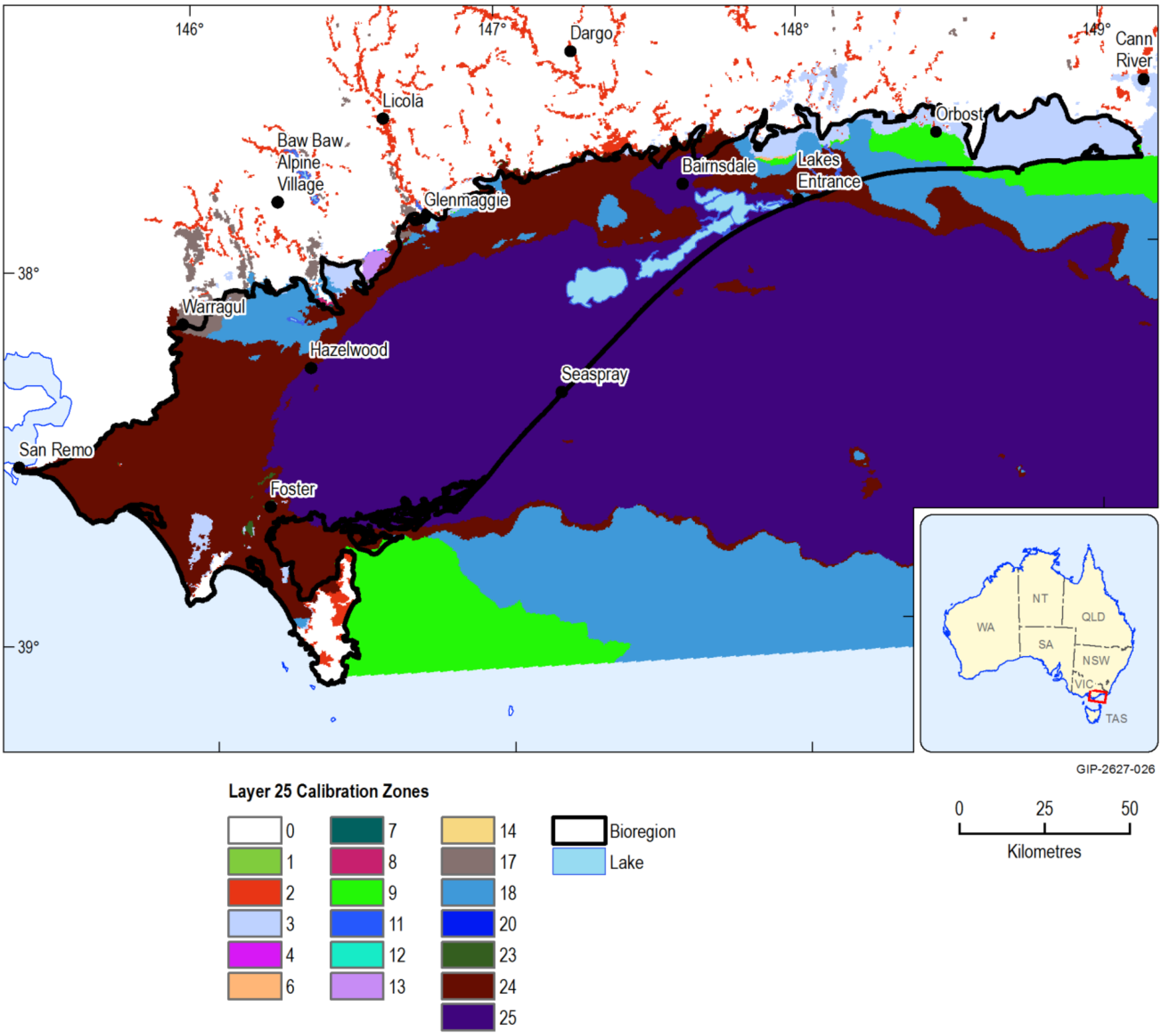


Figure 169 Spatial extent of zones used to calibrate modelled layer 25

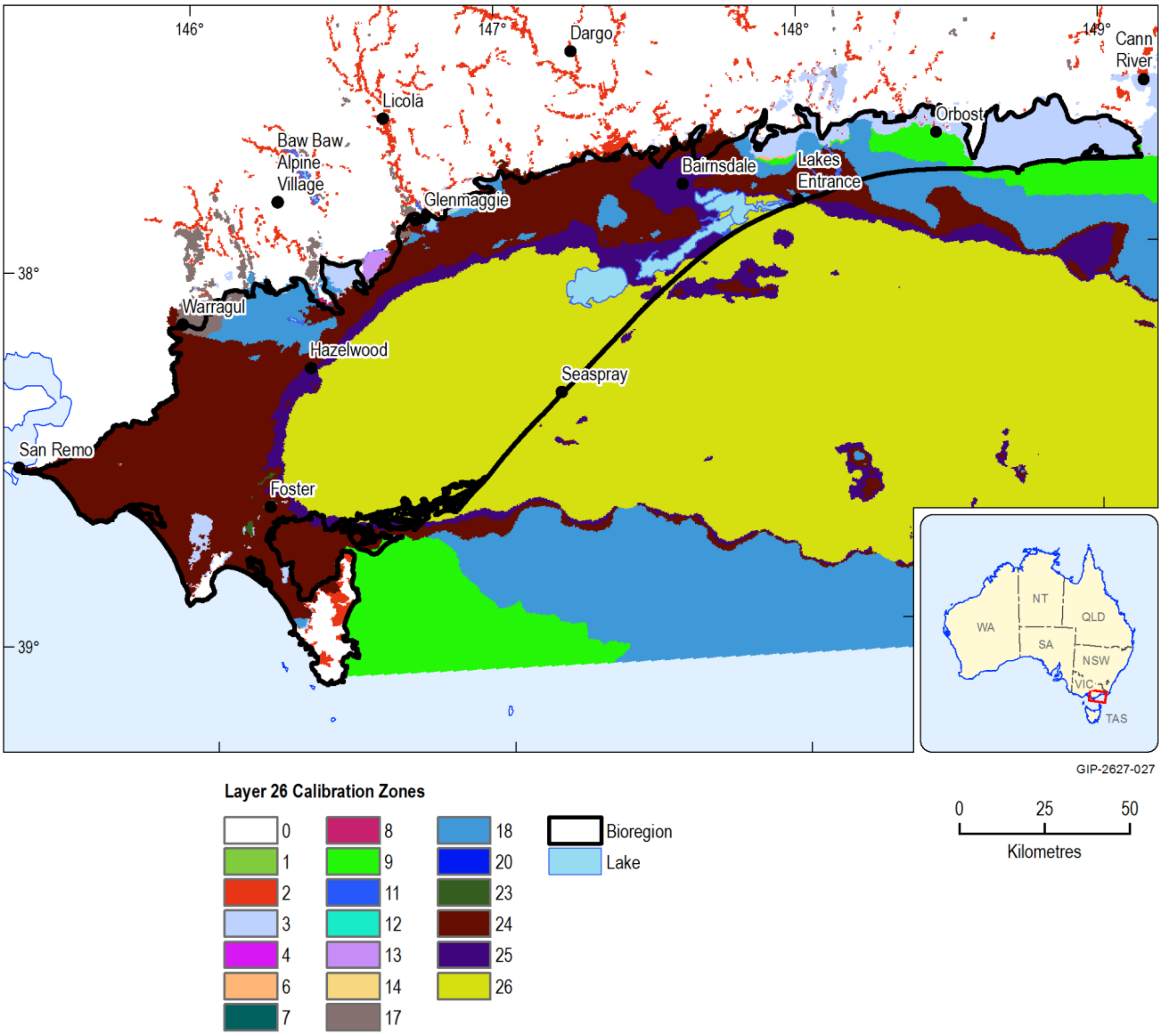


Figure 170 Spatial extent of zones used to calibrate modelled layer 26

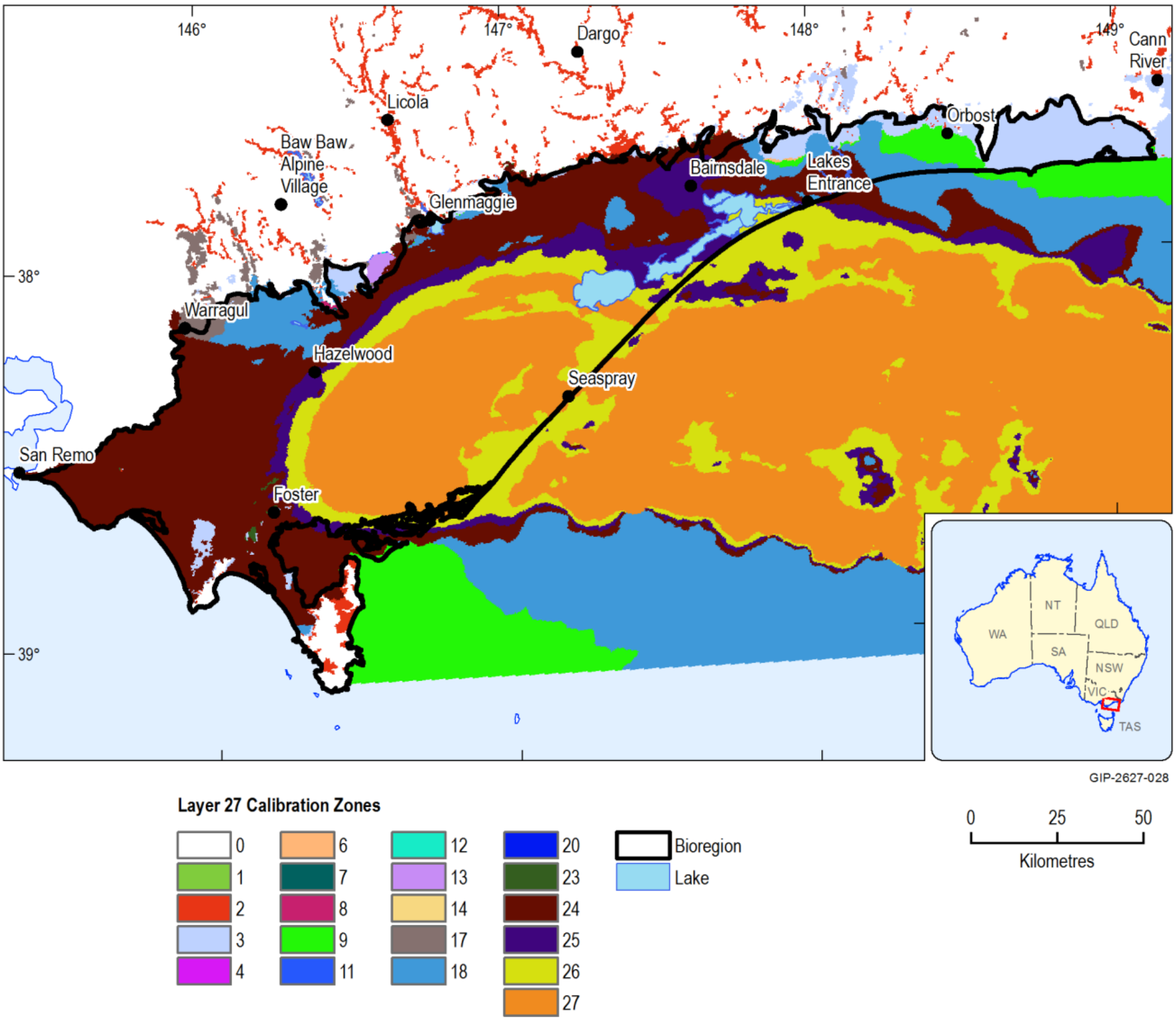


Figure 171 Spatial extent of zones used to calibrate modelled layer 27

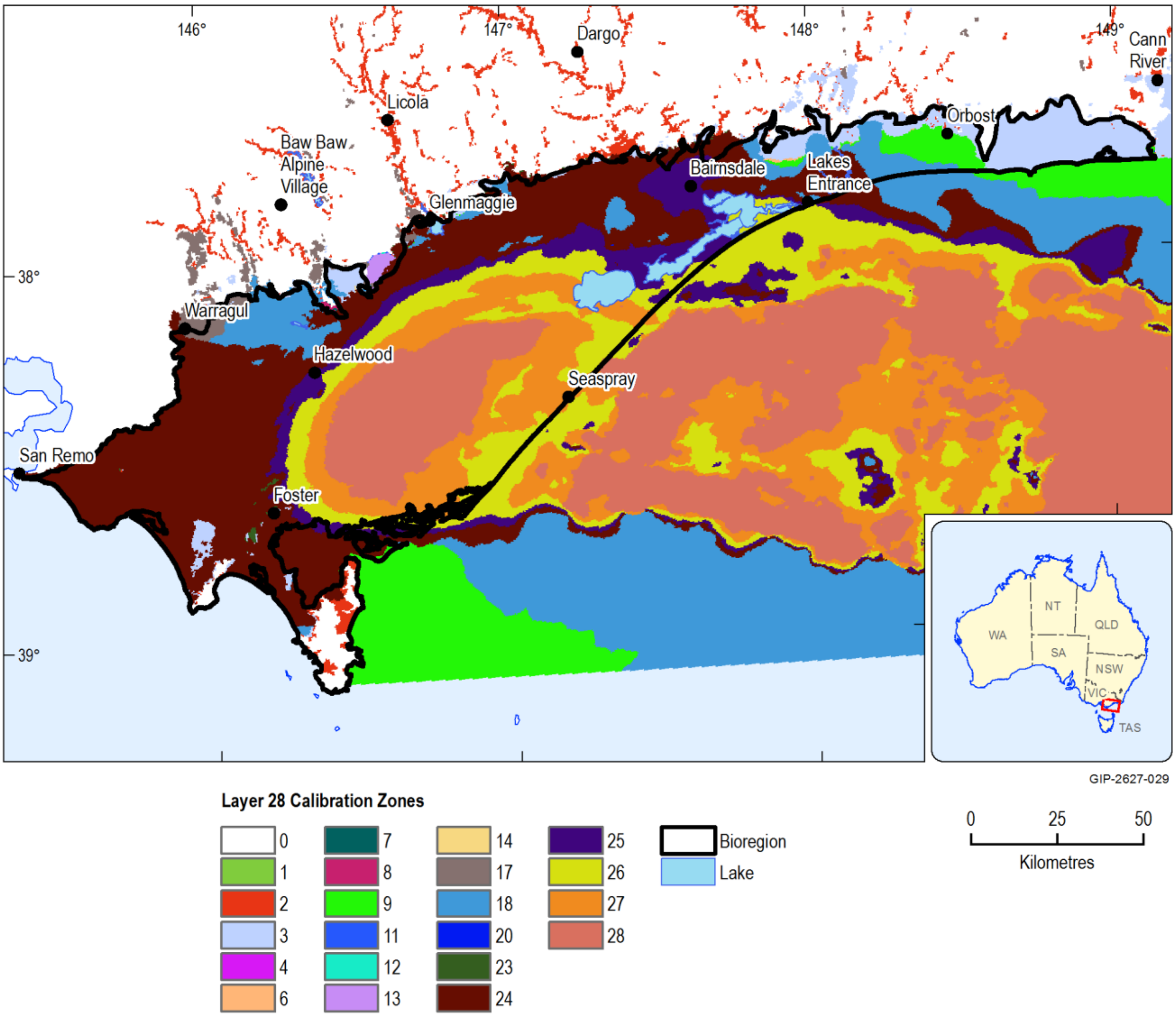


Figure 172 Spatial extent of zones used to calibrate modelled layer 28

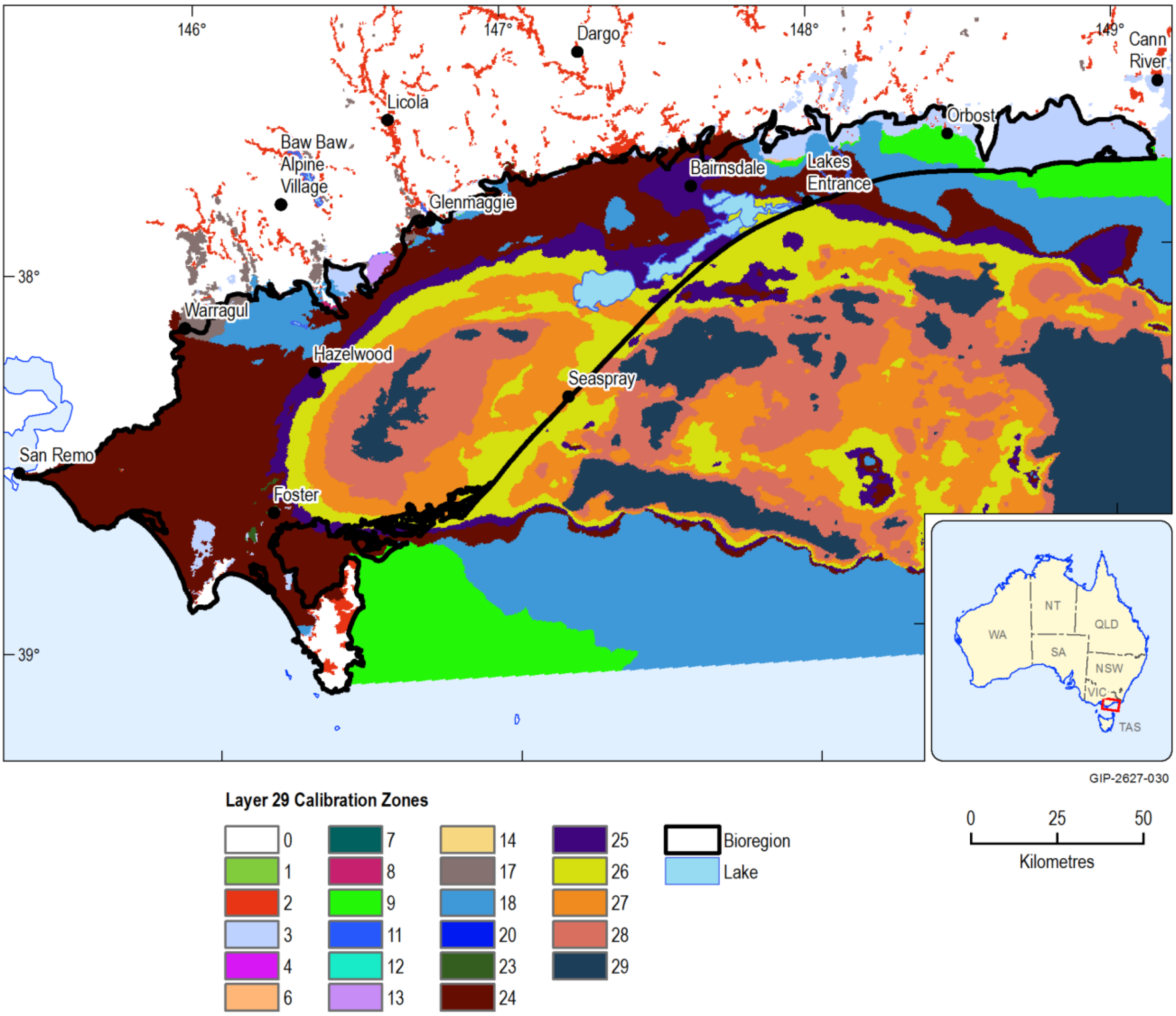


Figure 173 Spatial extent of zones used to calibrate modelled layer 29

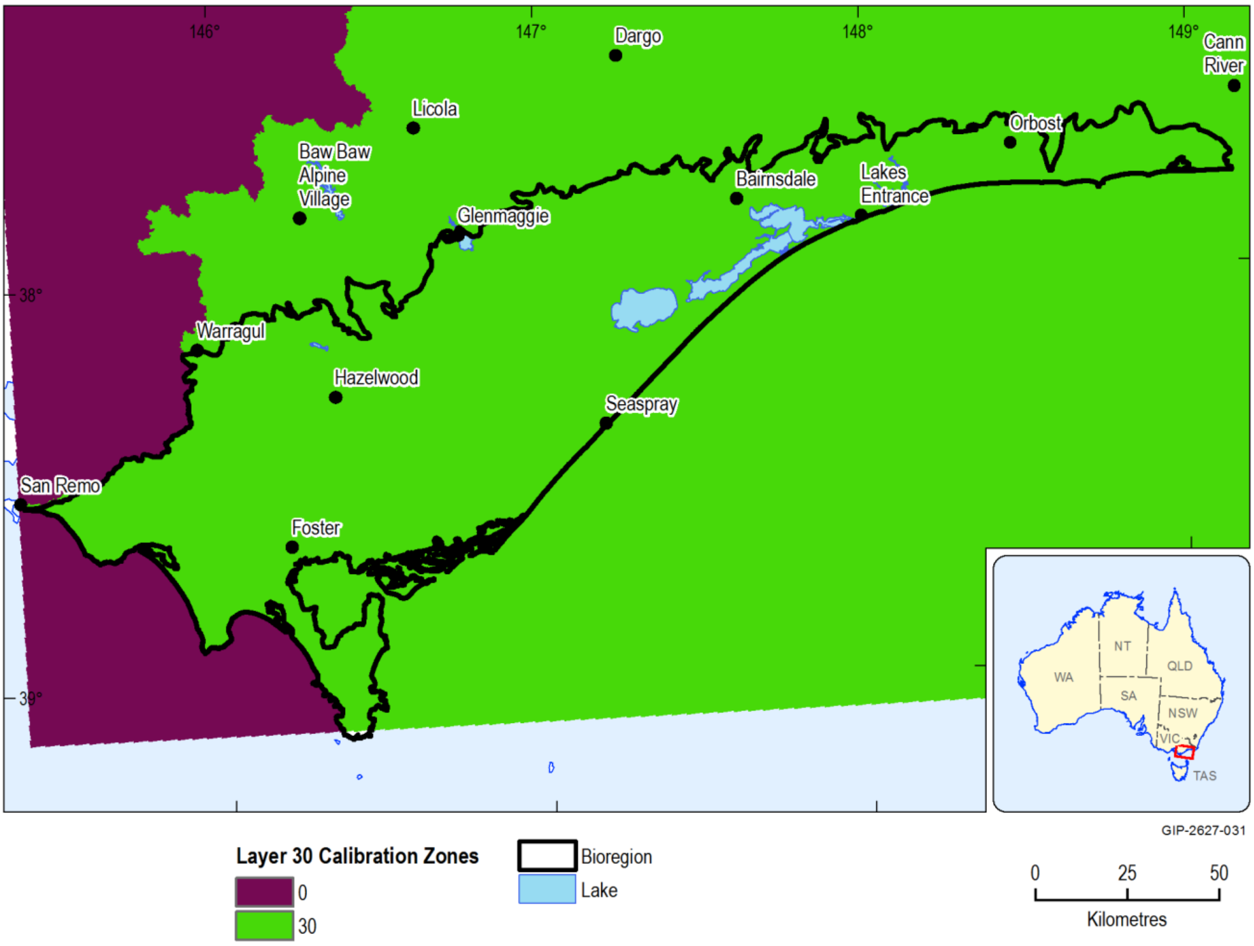


Figure 174 Spatial extent of zones used to calibrate modelled layer 30

2.6.2.7.4 Calibration criteria

The calibration procedure adopted a split calibration/verification approach in which the calibration period was 1990 to 1999 and the verification period was 2000 to 2012. Model calibration was based on matching groundwater hydrograph response and groundwater discharge to streams. In addition to these data sets, model predictions were also compared to mapped discharge extents in regions where this information was available.

Numerous statistical performance measures were applied to assess the goodness of fit model predicted and observed groundwater heads as summarised in Table 25. Analysis includes the coefficient of determination (CD) and the Nash–Sutcliffe index (NSI) (Nash and Sutcliffe, 1970). Each coefficient is defined by the number of observations n, measured data at time i, (Y_i), and the corresponding modelled prediction at time i (X_i). The CD value is a measure of the relationship between observed and simulated values whereas the NSI value indicates how well the plot of the observed versus simulated values fit the 1:1 line. If the CD and NSI values approach zero (or are negative), the model performance is considered to be unacceptable or poor. If the values are equal to one, the model prediction is considered perfect (Middlemis et al., 2000). An NSI value of 0.6 is viewed as “satisfactory” whereas an NSI of 0.8 or higher is considered “good” (Chiew et al., 1993).

Both manual and automated calibration procedures were adopted in this study. In the case of automated calibration three independent software packages were utilised, namely:

1. Groundwater Vistas
2. DOS version of PEST
3. A simplex optimisation approach.

A common underpinning data set was used by each package to enable a comparison of results. A zonal parameter distribution approach was employed.

Table 25 Statistical measure of model performance

Statistical Measure	Definition	Units	Description
Mean sum of squares	$MSSQ = \left(\frac{1}{N}\right)\sum_{i=1}^{N}(X_i - Y_i)^2$	m	MSSQ is the average of the square of the differences between predicted values and observed values.
Root mean square (RMS) error	$RMS = \sqrt{\left(\frac{1}{N}\right)\sum_{i=1}^{N}(X_i - Y_i)^2}$	m	Root Mean Square (RMS) error is the sample standard deviation of the differences between predicted values and observed values.
Scaled root mean square error	$SRMS = \frac{100\sqrt{\left(\frac{1}{N}\right)\sum_{i=1}^{N}(X_i - Y_i)^2}}{(Y_{max} - Y_{min})}$	%	Scales the RMS error to the range of the observed values and is expressed as a percentage. The SRMS is more meaningful than root mean square error as it is independent of scale.
Root mean fraction square error	$RMFS = 100\sqrt{\left(\frac{1}{N}\right)\sum_{i=1}^{N}\left(\frac{(X_i - Y_i)}{Y_i}\right)^2}$	%	RMFS represents the sample standard deviation of the differences between predicted values and observed values as a fraction of the observed value expressed as a percentage.
Scaled root mean fraction square error	$SRMFS = \frac{100\ \bar{Y}}{(Y_{max} - Y_{min})}\sqrt{\left(\frac{1}{N}\right)\sum_{i=1}^{N}\left(\frac{(X_i}{Y}\right.}$	%	Scales the RMFS error by the ratio of the mean observed value to the range of the observed values expressed as a percentage.
Mean sum of residual	$MSR = \left(\frac{1}{N}\right)\sum_{i=1}^{N}(X_i - Y_i)$	m	MSR or residual mean is not an unbiased estimator of the error variance.
Scaled mean sum of residuals	$SMSR = \frac{\left(\frac{1}{n}\right)\sum_{i=1}^{n}(X_i - Y_i)^2}{(Y_{max} - Y_{min})}$	%	As per Root Mean Square error but further scaled by the range of observation data and expressed as a percentage.
Coefficient of determination	$CD = \frac{\sum_{i=1}^{N}(Y_i - \bar{Y})^2}{\sum_{i=1}^{N}(X_i - \bar{Y})^2}$		Describes the causation of change in *Y* by changes in *X*.
Nash–Sutcliffe index	$NSI = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$		The NSI value is a measure of the relationship between observed and simulated values.

2.6.2.7.5 Steady-state predictions

The steady-state model assumed 1970 pre-development conditions in which there were no groundwater extractions. Simulated steady-state water balance results for the active model domain are summarised in Table 26. It is noteworthy that all domain cells remained saturated. The percentage mass balance closure error reported by MODFLOW-2005 was 0.7%, which satisfies the pre-defined target.

Table 26 Steady-state mass balance predictions

	Flow in ML/day	Flow out ML/day	Net flow ML/day	% Recharge
Recharge	9737.7		9737.7	
Evapotranspiration		4002	–4002	41
Major rivers	15	353	–338	4
Drains/streams		3468	–3468	36
Constant head	777	2632	–1855	19

Water balance results suggest that:

- 40% of groundwater recharge discharges to river and drains
- 41% of groundwater recharge is "lost" through evapotranspiration
- 19% of groundwater recharge is discharged as a net outflow across the model boundaries predominantly through flux offshore.

The calibration statistics for the steady-state groundwater model based on 71 observation points are summarised in Table 27. These target statistics meet the calibration criteria as specified by the project. The observed versus computed target values are shown in Figure 175 whereas the observed versus residual error is shown in Figure 176.

Table 27 Steady-state model calibration statistics

Statistic	Code	Unit	Steady-state
Mean sum of squares	MSSQ	m	3.50
Root mean square	RMS	m	1.87
Scale root mean square	SRMS	%	5.34
Root mean fraction square	RMFS	%	10.24
Scaled root mean fraction square	SRMFS	%	0.60
Sum of residuals	SR	m	398.07
Mean sum of residuals	MSR	m	0.52
Scaled mean sum of residuals	SMSR	%	1.49
Coefficient of determination	CD		0.66
Nash–Sutcliffe index	NSI		0.69

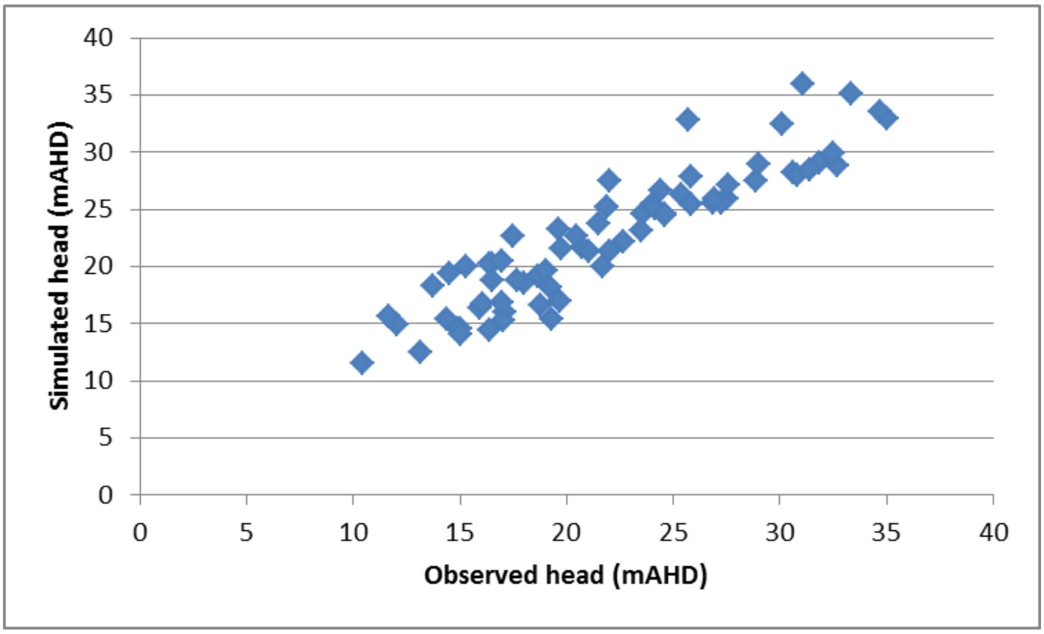


Figure 175 Observed versus computed steady-state heads (mAHD)

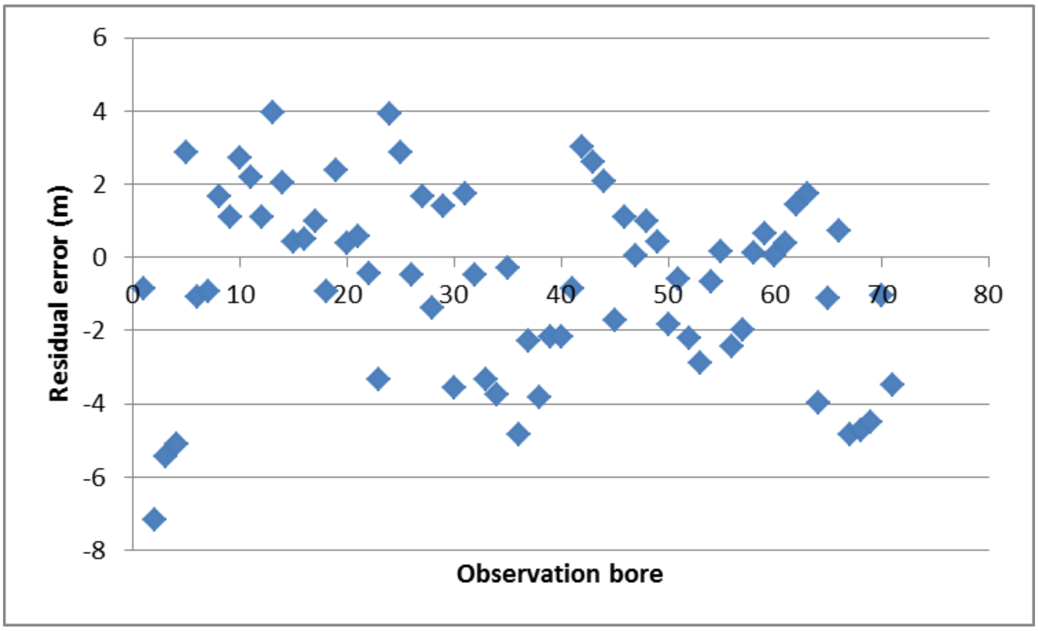


Figure 176 Residual error (observed head – modelled head) (m) for each steady-state calibration bore

The simulated 1970 unconfined potentiometric surface (water table) and depth-to-water table map across the entire model domain are shown in Figure 177 and Figure 178 respectively.

Visual comparison of the Victorian SAFE depth to water table map (Figure 179) with the steady-state simulated depth to water table map shows the water table surface is reasonable within the alluvial systems, however in some upland locations the water table appears to be in greater connection with surface features than presented in the Victorian Aquifer Framework (VAF) data. This is not considered a significant issue as these areas are well beyond the zone of interest.

It must be noted that the VAF depth to water table map was derived using a combination of terrain analysis and interpolated bore data, and in part based on proximity to streams within the exposed basement areas. Additionally, the VAF reflects the 1990 conditions whereas the simulated steady-state depth to water table represents pre-development conditions. As such, it is expected that that the simulated steady-state depth to water table map would have a greater area of shallow water table than that reported in the VAF spatial layer.

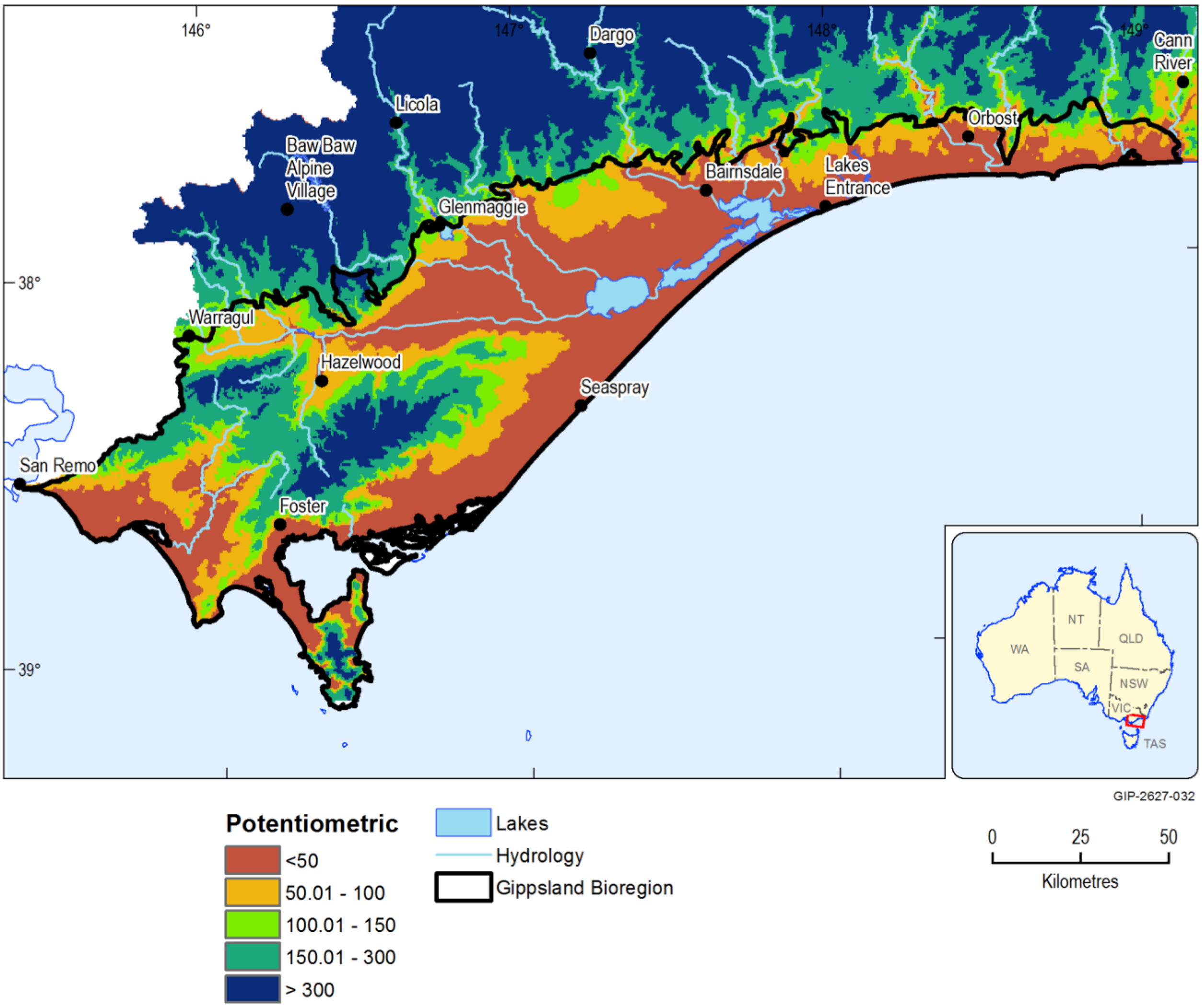


Figure 177 Simulated 1970 unconfined aquifer potentiometric surface (mAHD)

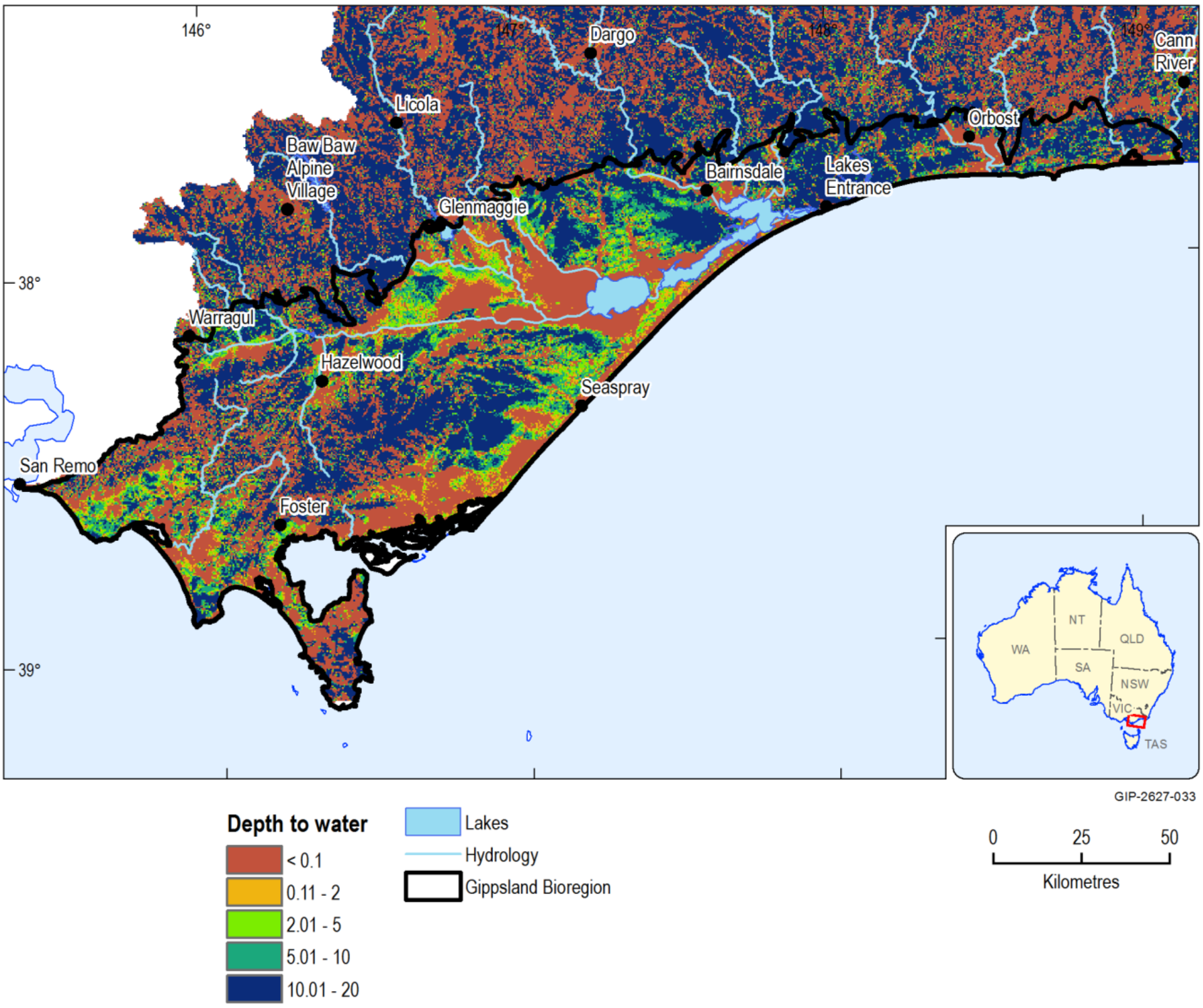


Figure 178 Simulated 1970 steady-state depth to water table (m)

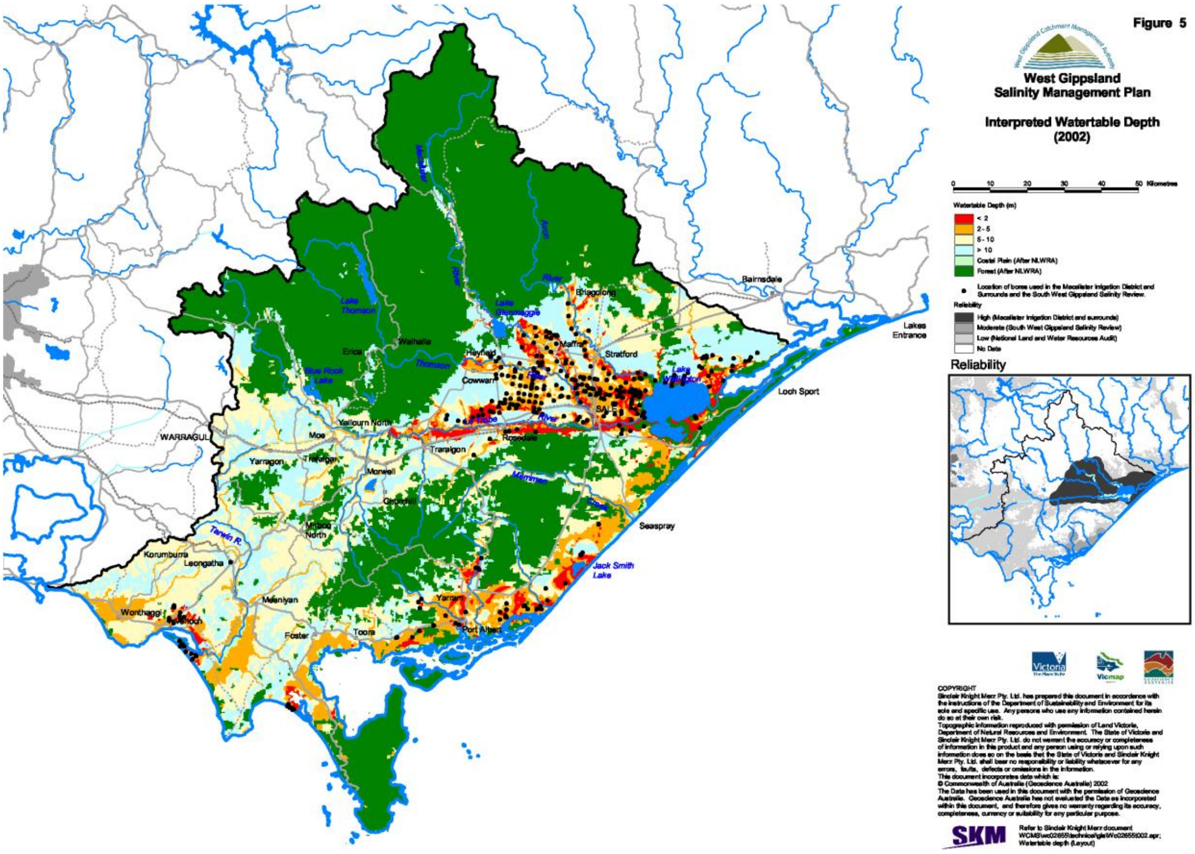


Figure 179 1990 water table depth (m) within the West Gippsland CMA region

2.6.2.7.6 Transient predictions

Simulated transient volumetric water balance components for the active model domain are shown in Figure 180. Presented results clearly show the transition phase from the initial steady-state conditions to the calibration period commencing in 1990. Also of note is the lack of seasonal responses during the 1970 to 1990 simulation period during which annual stress periods have been assigned.

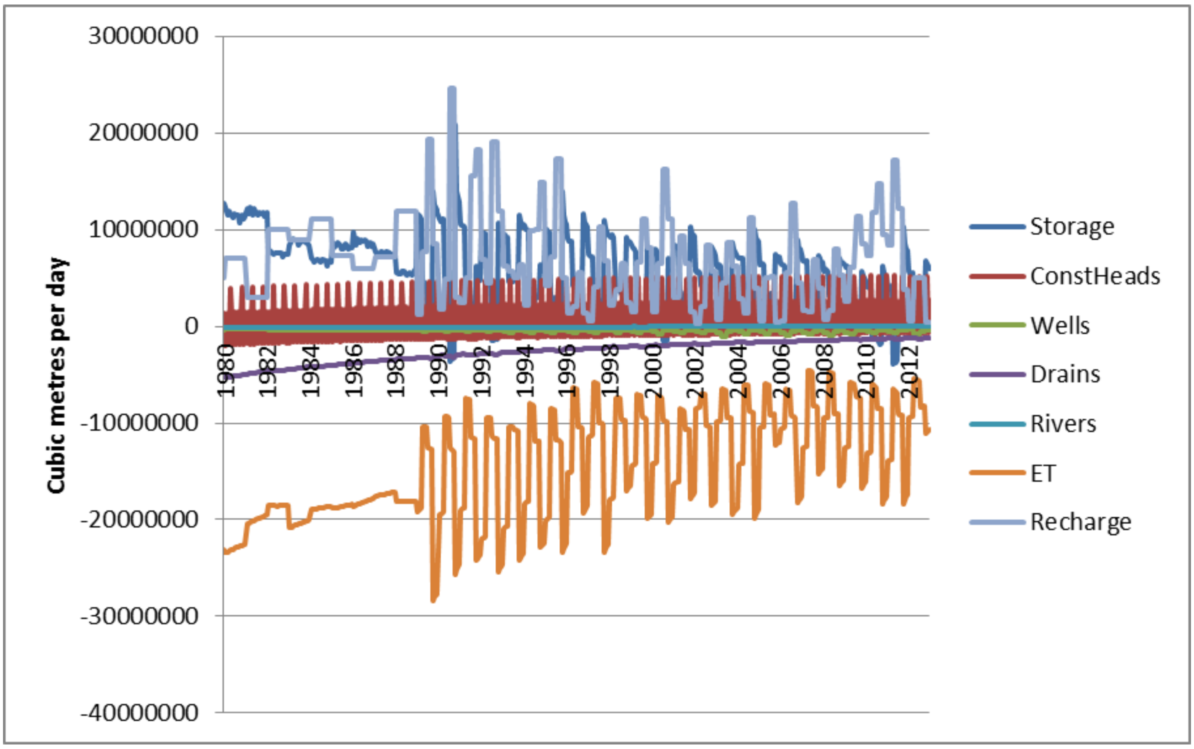


Figure 180 Transient model mass balance components (m^3/day per time step)

Calibration statistics

The calibration statistics for the transient groundwater model based on 88,799 observation points are summarised in Table 28 for the transition calibration and verification periods. The transient calibration statistics suggest there is a poor match between the modelled and observed data during the initial 20 years of simulation, which is also when the stress periods are large and the transition from the pseudo steady-state conditions would have the greatest impact on model predictions. This suggests that the simulated pseudo steady-state solution describes the 1970 groundwater condition poorly. Importantly the calibration statistics improve during the 1990-1999 calibration period as evidenced by an improved scaled RMS of 5.62% compared to the pre-calibration period scaled RMS of 8.82%. The 2000–2010 verification period has improved calibration statistics with a scaled RMS of 1.42%, a mean sum of residuals of 5 m and a coefficient of determination of 0.9. Key calibration criteria traces are presented in Figure 181 to Figure 184.

Table 28 Transient model calibration statistics

Name of statistics	Code	Unit	1970–1989	1990–1999	2000–2010
Number of observations			16050	30158	42591
Mean Sum of Squares	MSSQ	m	876.30	354.53	231.78
Root Mean Square	RMS	m	29.60	18.83	15.22
Scale Root Mean Square	SRMS	%	8.82	5.62	1.42
Root Mean Fraction Square	RMFS	%	42186.37	5403.267	10633.07
Scaled Root Mean Fraction Square	SRMFS	%	3318.30	271.58	139.77
Sum of Residuals	SR	m	59826.58	221472.12	223509.96
Mean Sum of Residuals	MSR	m	3.73	7.34	5.25
Scaled Mean Sum of Residuals	SMSR	%	1.11	2.19	0.49
Coefficient of Determination	CD		0.45	0.68	0.90

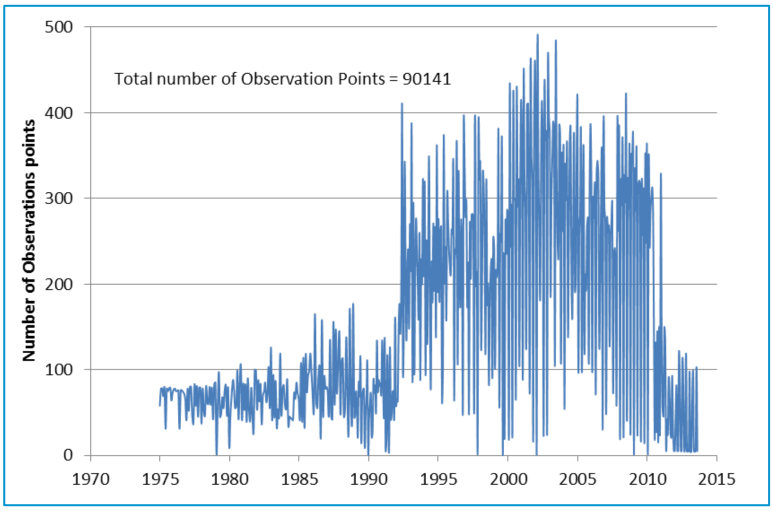


Figure 181 Number of observation points throughout the simulation period

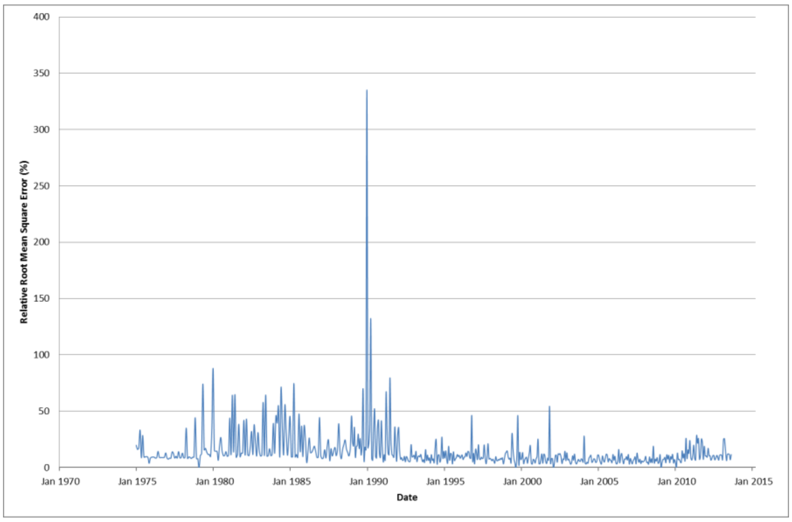


Figure 182 Temporal trace of RMS error (%) throughout simulation period

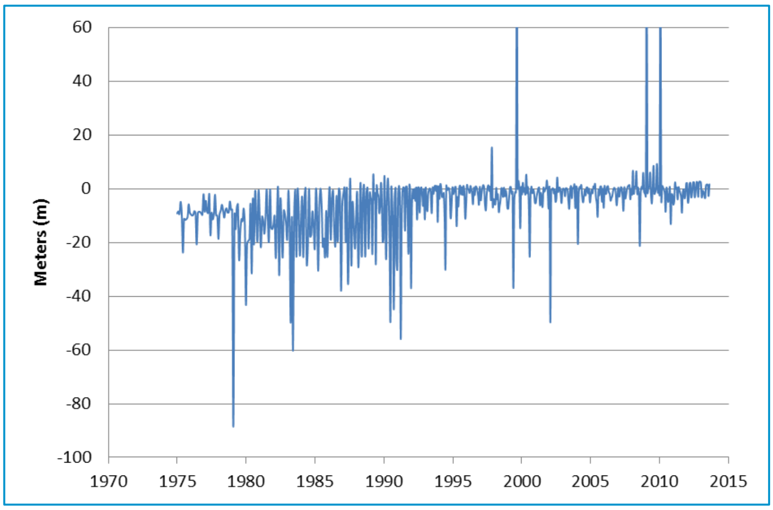


Figure 183 Temporal trace of mean residual error (m) throughout simulation period

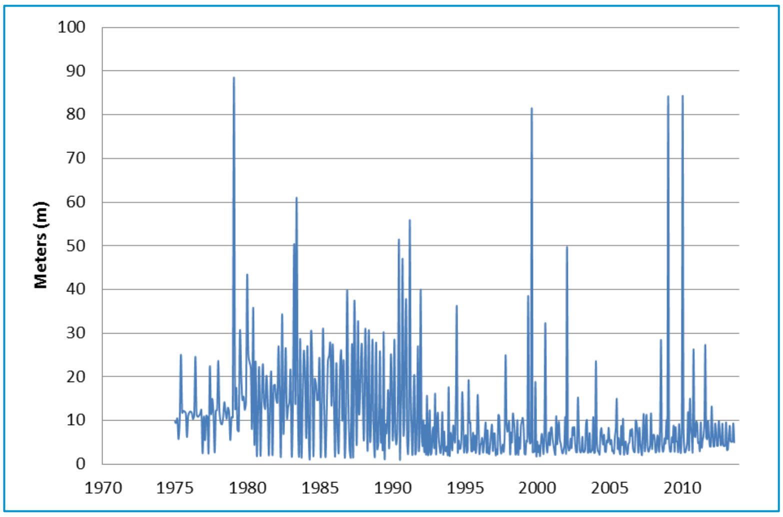


Figure 184 Temporal trace of mean absolute error (m) throughout the simulation period

Spatial residual error

The spatial distributions of residual errors are presented in Figure 185, Figure 186, Figure 187 and Figure 188 for 1980, 1990, 2000 and 2010 respectively. The mean residual water level is defined such that negative numbers refer to points where predicted hydraulic head values are higher than observed and positive values indicate that predicted hydraulic head values are lower than observed.

Results shown in Figures 42 to 45 suggest that the model over predicts the hydraulic heads in the outcropped regions and under predicts the heads in the lower parts of the landscape. The greatest errors are shown to be in the outcropping regions of the Strzelecki Formation suggesting that the model attribution associated with model layer 23 requires further analysis. This is consistent with observations reported in the Observational Analysis companion product (2.1-2.2) for the Gippsland Basin bioregion that considered the hydraulic conductivities attributed to zones 23–29 were on the lower bounds of previously reported values

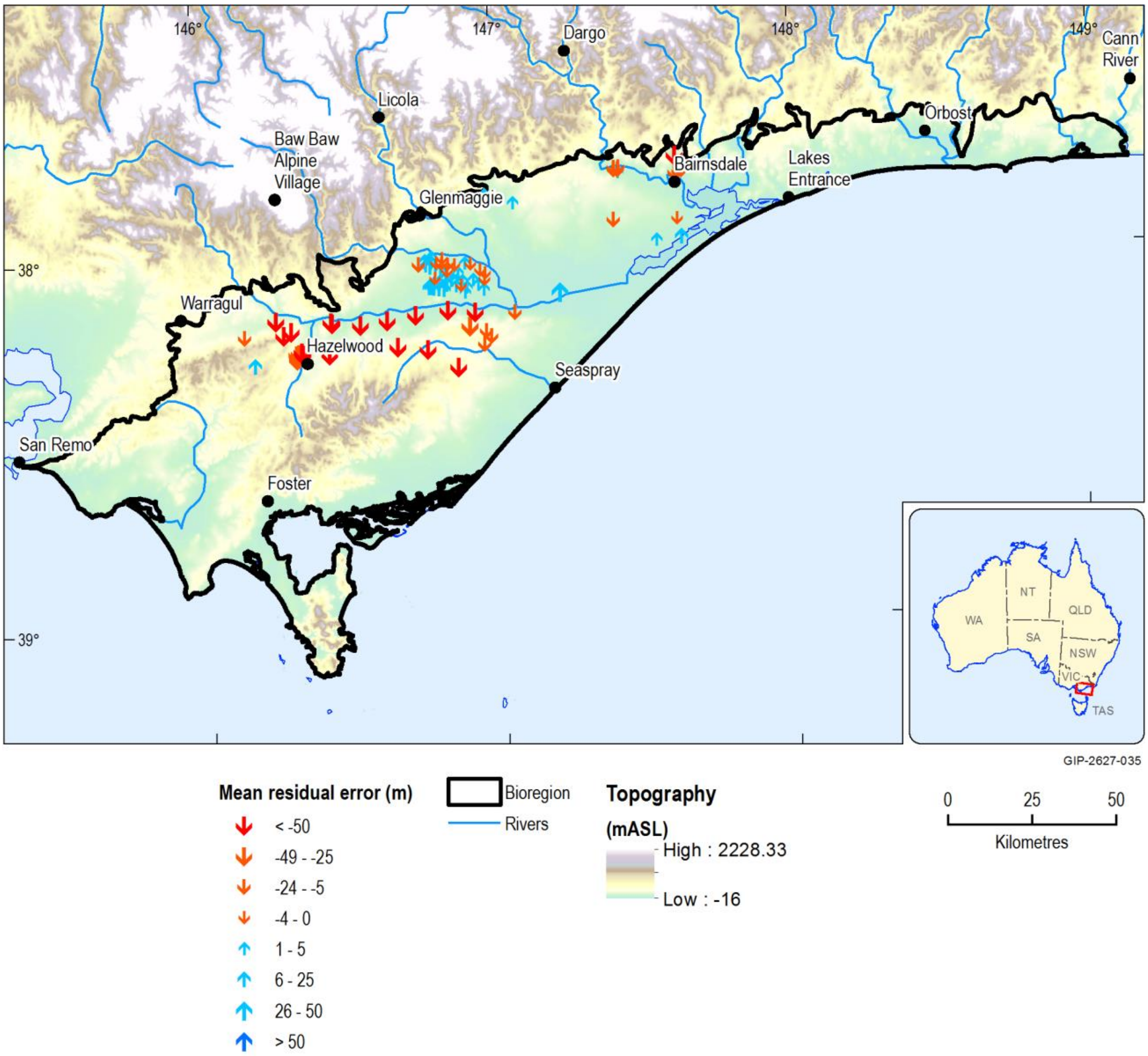


Figure 185 Spatial mean residual water level error (m) for 1980 based on observed and predicted heads

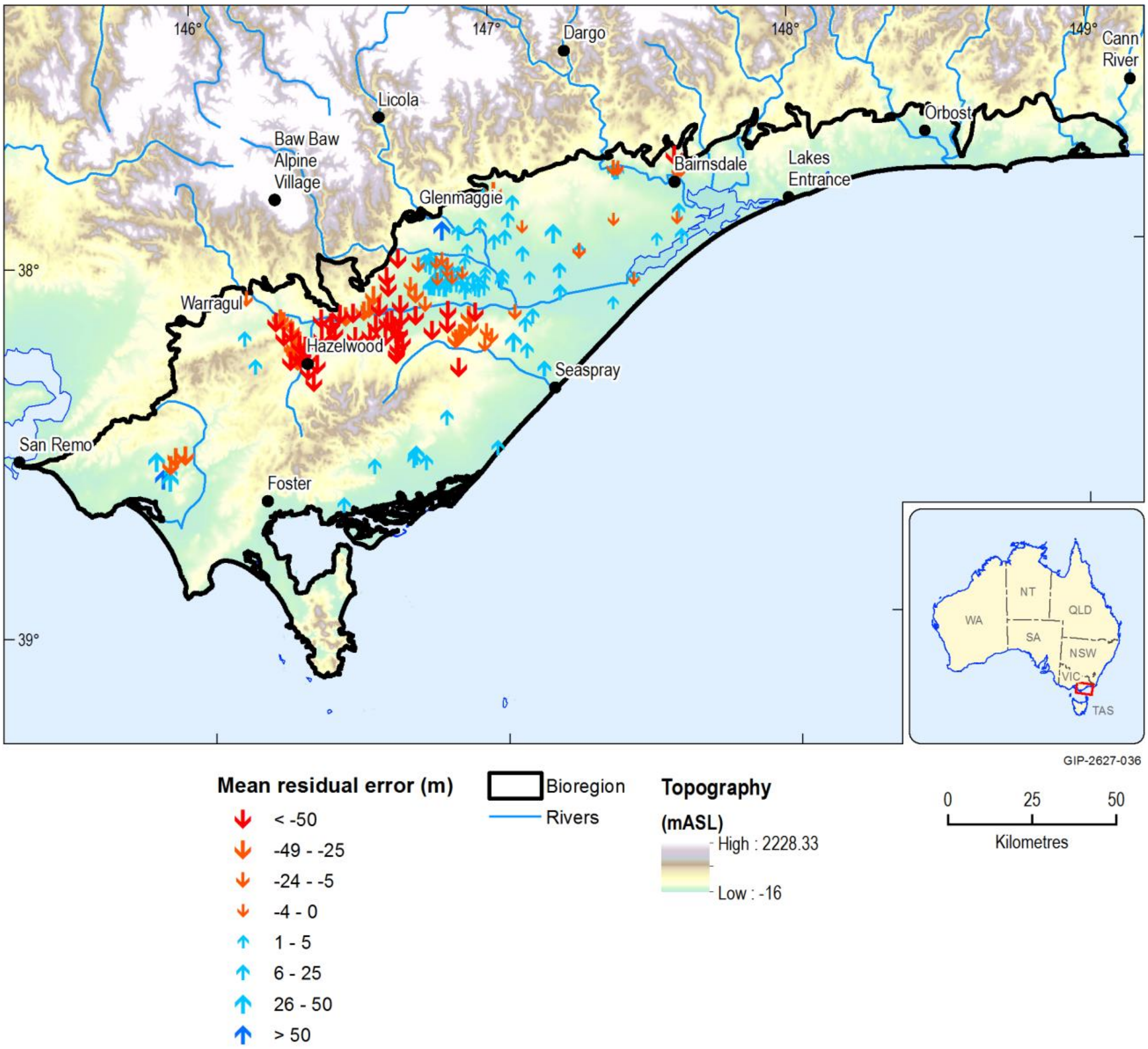


Figure 186 Spatial mean residual water level error (m) for 1990 based on observed and predicted heads

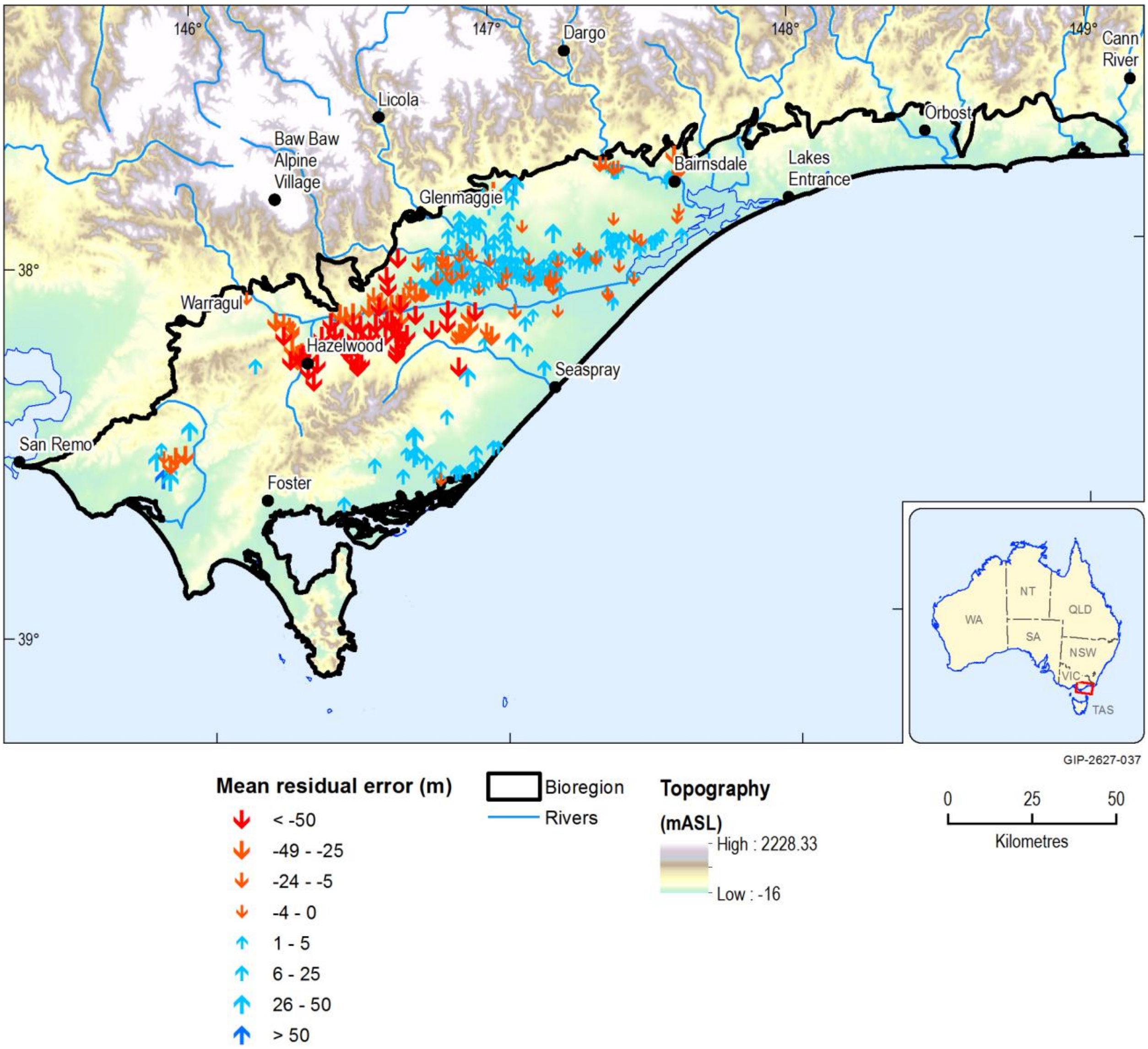


Figure 187 Spatial mean residual water level error (m) for 2000 based on observed and predicted heads

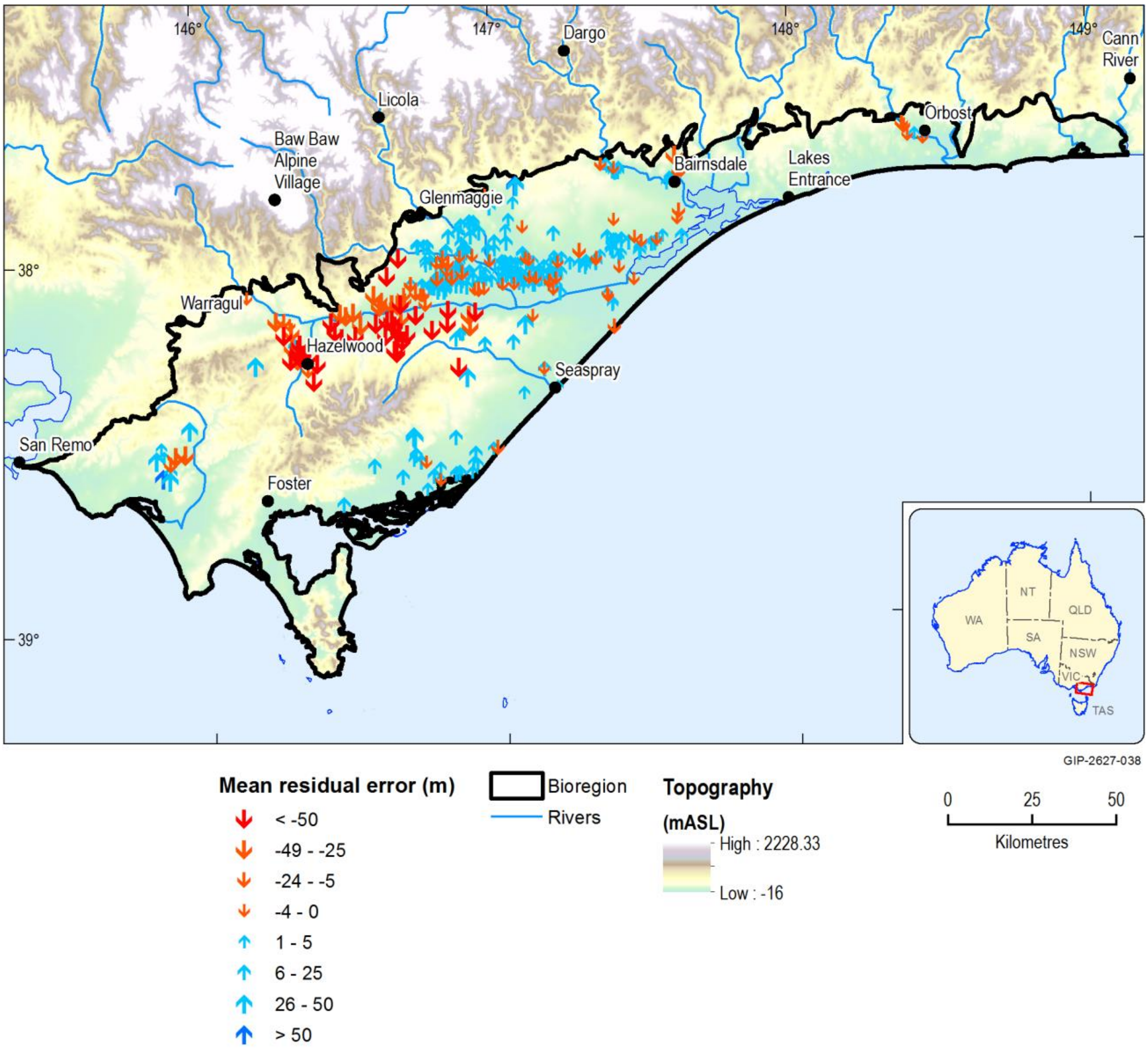


Figure 188 Spatial mean residual water level error (m) for 2010 based on observed and predicted heads

2.6.2.7.7 Sensitivity analysis

A comprehensive analysis was undertaken to assess the sensitivity of key modelled outputs to variations in input data. Modelled outputs considered included baseflow rates, saturated area and groundwater discharges (evapotranspiration, boundary fluxes and aquifer interflows). The sensitivity analysis procedure involved altering by up to three orders of magnitude the calibrated input data sets (including horizontal hydraulic conductivities, specific storage, specific yield, vertical hydraulic conductivities, recharge, maximum evapotranspiration rates, river and boundary conductance terms) and recording the groundwater response relative to the calibrated condition. Each input data set was systematically modified while maintaining all other input data. In total, approximately 4,200 simulations were undertaken to test the robustness of the groundwater model and the uniqueness of the combination of input data required to meet the calibration criteria.

The sensitivity analysis was undertaken to assess the performance of the groundwater model simulation to changes in various input parameter values. The model performance was assessed based on scaled RMS, coefficient of determination and NSI criteria (see Section 4) using observed and predicated calibration bore hydrograph responses. A total of 4,200 simulations were examined in detail, in which changes in recharge, groundwater evapotranspiration rates, river conductance, horizontal and vertical hydraulic conductivities, specific storage and specific yields were modified by three orders of magnitude from the calibrated values. Although 4,200 simulations were examined in detail, model performance results based on variations in recharge, groundwater evapotranspiration rates, river conductance, drain conductance and horizontal hydraulic conductivities are presented for the steady-state model in Figure 189 to Figure 192 respectively.

The sensitivity of the model to recharge estimates is shown in Figure 189. This figure shows the variation in MAE, coefficient of determination and NSI criteria due to altered recharge. The trajectory of each response curve reflects the solution uniqueness and stability of the model. The flatter the curve, the less sensitive the output to the associated model attribute.

Results from the sensitivity analysis show a comparatively high sensitivity of simulated shallow water table extent to variations in recharge and maximum groundwater evapotranspiration. This is to be expected as these parameter changes are applied across large extents of the model, whereas hydraulic conductivity changes are applied on a zone by zone basis which may be of minor/limited areal extents. A similar outcome applies to river conductance changes which impact localised processes and is limited by the density of the river network incorporated in the model.

In terms of the sensitivity of predicted baseflow to parameter change, the most significant parameters are (in order of significance) recharge, potential groundwater evapotranspiration rates and river conductance. The least significant parameters are those associated with the deeper aquifers.

With respect to the modelled area of shallow water table, the most significant parameters are (in order of significance) recharge, potential groundwater evapotranspiration rates and conductivities of the unconfined aquifers.

Based on this analysis, model uncertainty is most strongly impacted by uncertainty in the estimates of recharge and potential groundwater evapotranspiration rates. The hydraulic conductivities of the unconfined and outcropping aquifers also have significant influence on predicted baseflow and water table extent.

In general, the sensitivity analysis show model parameters generally fit within type I or II classification as described by Middlemis et al. (2000).

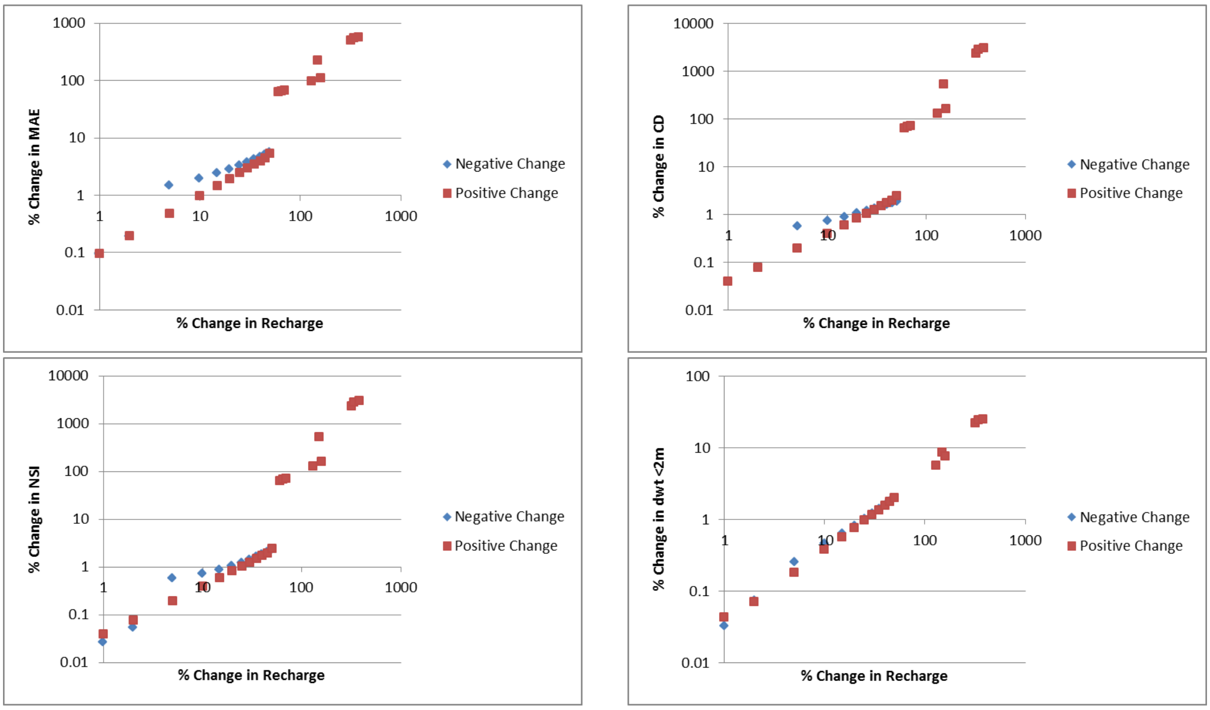
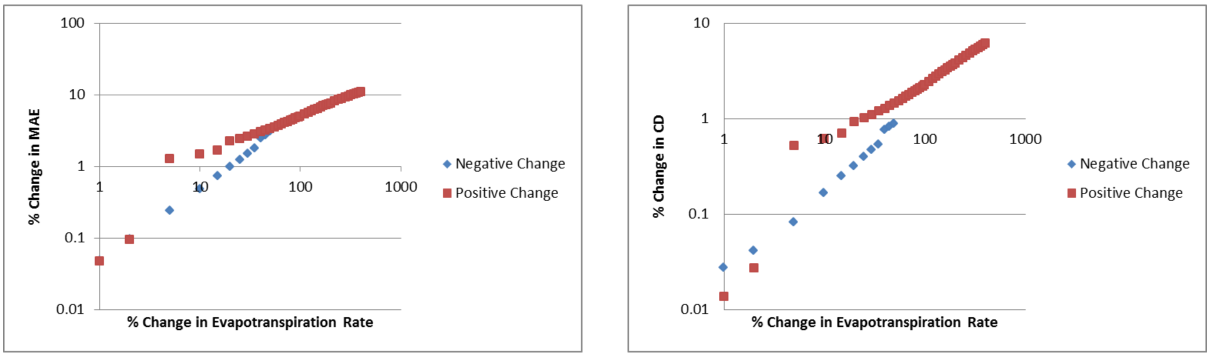


Figure 189 Sensitivity of the steady-state model to variations in recharge



2.6.2.7.7 Sensitivity analysis

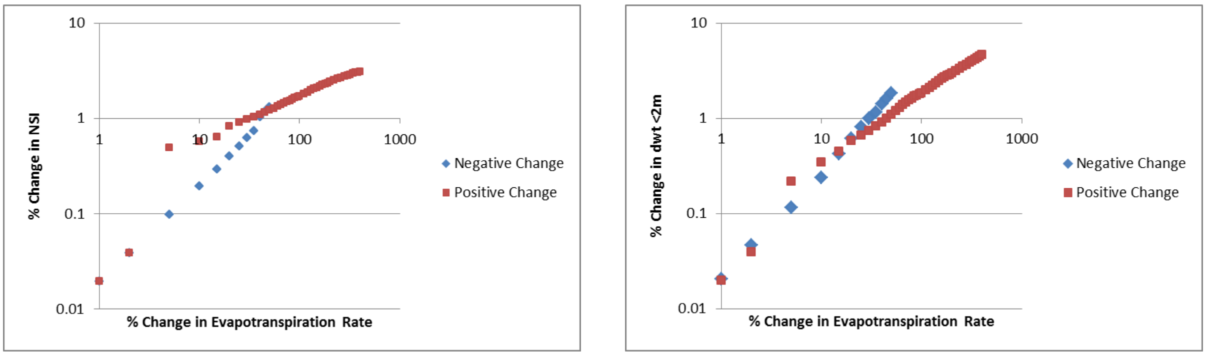


Figure 190 Sensitivity of the steady-state model to variations in potential groundwater evapotranspiration rate

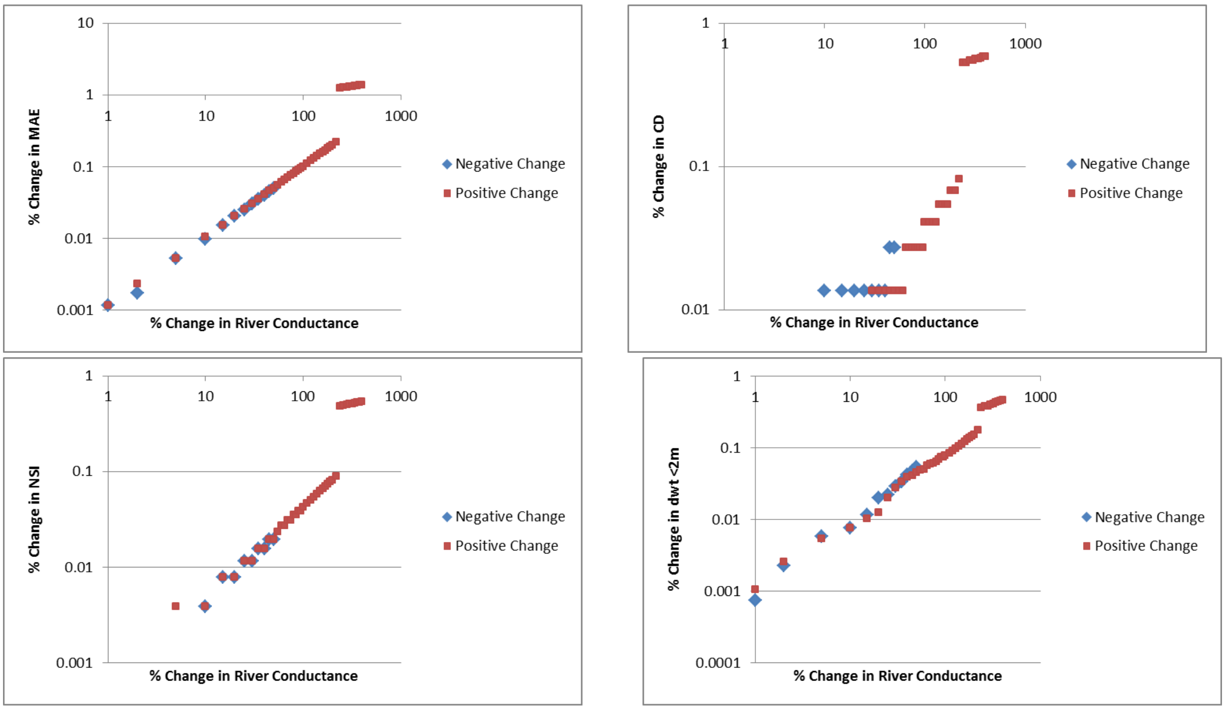
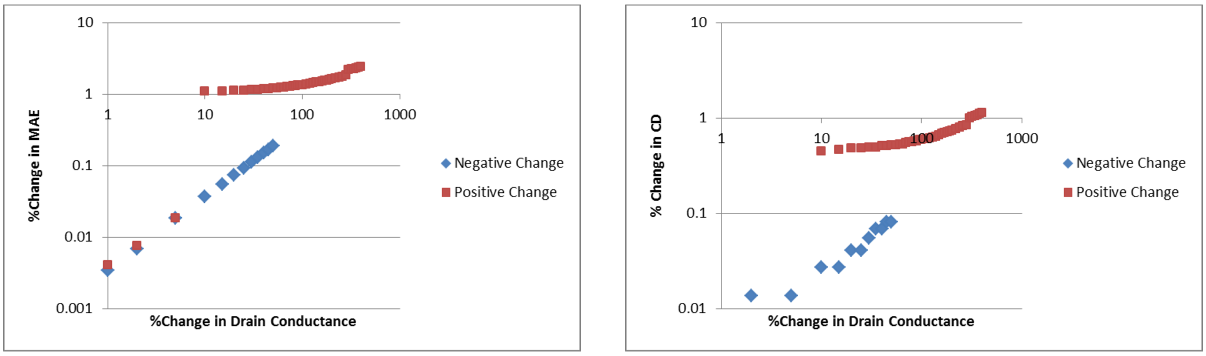


Figure 191 Sensitivity of the steady-state model to variations in river conductance



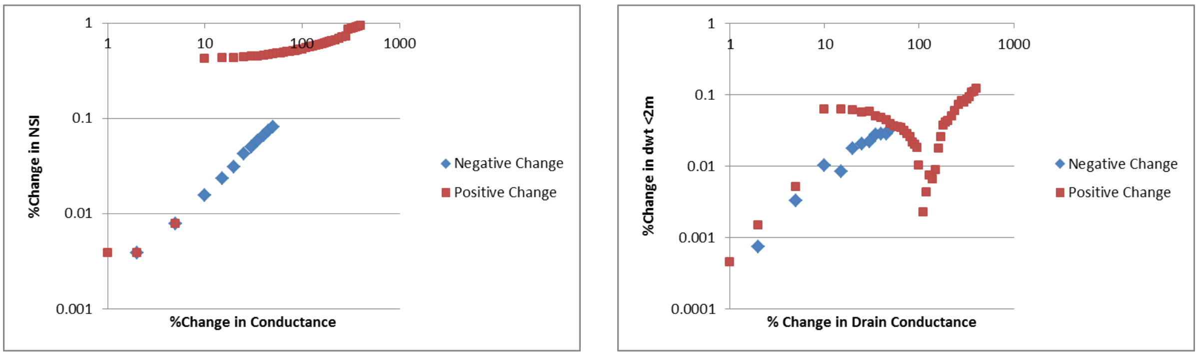


Figure 192 Sensitivity of the steady-state model to variations in drain conductance

2.6.2.7.8 CRDP predictions

Section 2.6.2.1.5 outlines the methodology in which the distributed multi-layered groundwater model was used at the basin scale to account for the CRDP under a climate change signal. The future climate change projections translated into an average reduction in rainfall of 6.8% from 2073 to 2102 relative to the 1983 to 2012 conditions as reported in Section 2.5.2 of companion product 2.5 for the Gippsland Basin bioregion. The resultant reduction in surface water inflows and groundwater baseflows was predicted to be 12% and 75% respectively. It is in this context that the CRDP simulation results are presented.

The modelling assumed that the expansion of existing open-cut mine pits occurs in a sequenced and progressive development phasing based on mine work plans. The rate of development was set such that mine development was completed by the expected mine closure date. Model simulation targets were based on matching estimated mine dewatering volumes derived from previous groundwater modelling (GHD, 2014b) and the stabilisation of groundwater heads within the basement of the mine.

The current parameterisation results in the bulk of the water extracted from expanded open-cut coal mine dewatering to be sourced from the aquifer beneath the associated target coal seam where the hydraulic conductivity and storages are considered to be higher. There is therefore a higher probability of this parameterisation to over predict groundwater extraction volumes associated with the CRDP. The predicted extraction volumes associated with the CRDP for the Hazelwood, Loy Yang and Yallourn mines are shown in Figure 193, Figure 194 and Figure 195 respectively.

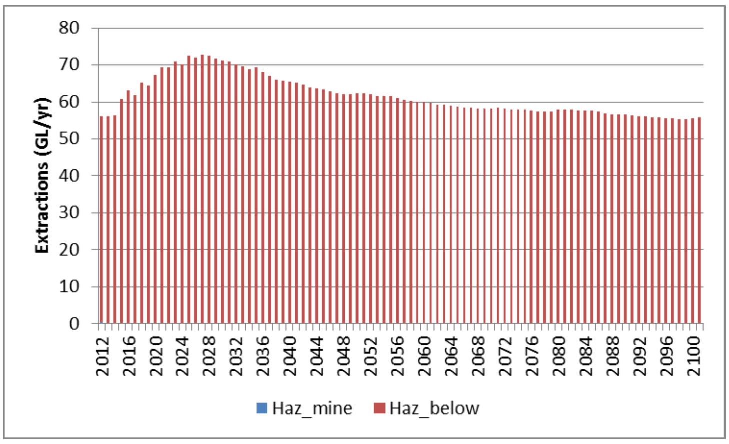


Figure 193 Predicted time varying mine dewatering extraction volume for the Hazelwood mine required to meet the CRDP targets. The predicted volume is the sum of the extraction from the base of the M2A seam (Haz_mine) and the aquifer below (Haz_below)

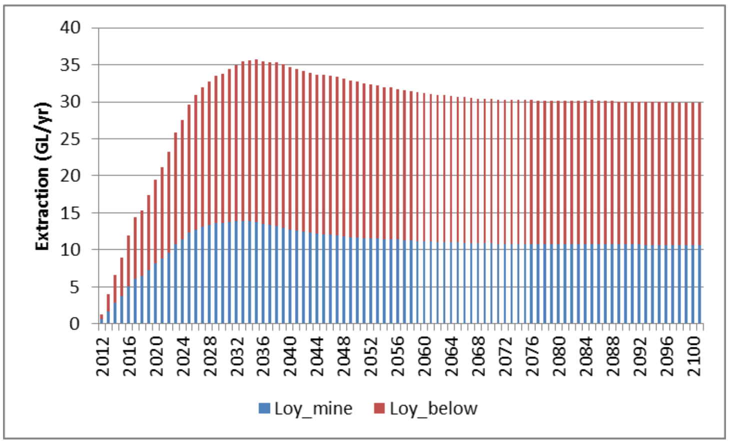


Figure 194 Predicted time varying mine dewatering extraction volume for the Loy Yang mine required to meet the CRDP targets. The predicted volume is the sum of the extraction from the base of the M2A seam (Loy_mine) and the aquifer below (Loy_below)

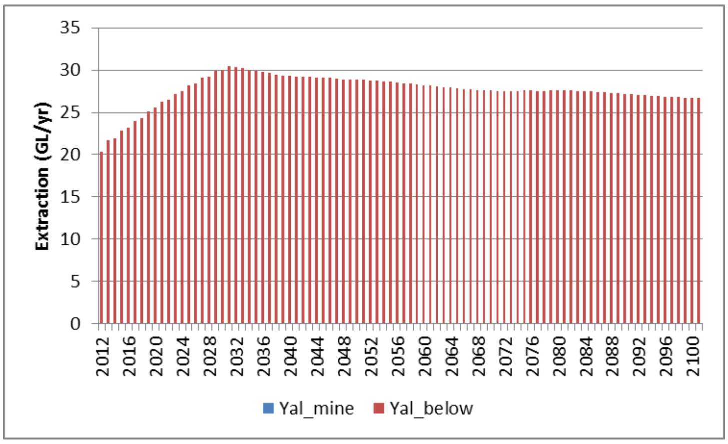


Figure 195 Predicted time varying mine dewatering extraction volume for the Yallourn mine required to meet the CRDP targets. The predicted volume is the sum of the extraction from the base of the Yallourn coal seam (Yal_mine) and the aquifer below (Yal_below)

The change in water table elevation within each open-cut mine pit during the coal mine development phasing is shown in Figure 196. At the end of the simulation the average hydraulic heads within the mine pits were -52 mAHD, -92 mAHD and 12 mAHD for the Hazelwood, Loy Yang and Yallourn mines respectively with 37% and 47% of the Hazelwood and Loy Yang mine cells becoming dry.

The impact of climate change and projected baseline groundwater extractions on the predicted depth to water table relative to the 2012 condition (Figure 197) at 2042, 2072 and 2102 are shown in Figure 198, Figure 199 and Figure 200 respectively. In general, the depth to water table from ground surface increases on the basin margins and outcropped areas due to the reduced recharge whilst in predominantly lowland alluvial systems the depth to water table is shallower due to a reduction in groundwater extractions.

The impact of the additional coal resource development (depth to water table under the CRDP relative to the corresponding baseline condition at 2042, 2072 and 2102) is shown in Figure 201 to Figure 203 respectively. As outlined in Section 2.5.2 of companion product 2.5 for the Gippsland

Basin bioregion, the CRDP has most impact on those regions in close proximity to the proposed open-cut coal mine pits. Simulation results estimate that the greatest spatial impact is likely to occur at 2072. This is consistent with the timing of the peak reduction in annual baseflow (ML/yr) to the Latrobe River as shown in Figure 204.

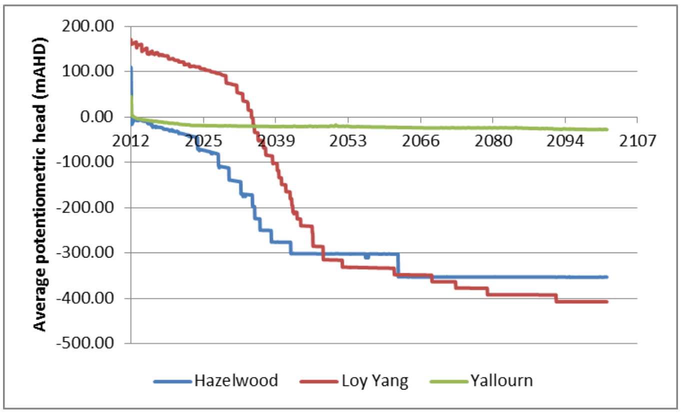


Figure 196 Average water table elevation within the open cut mine pits in response to CRDP mine work plans

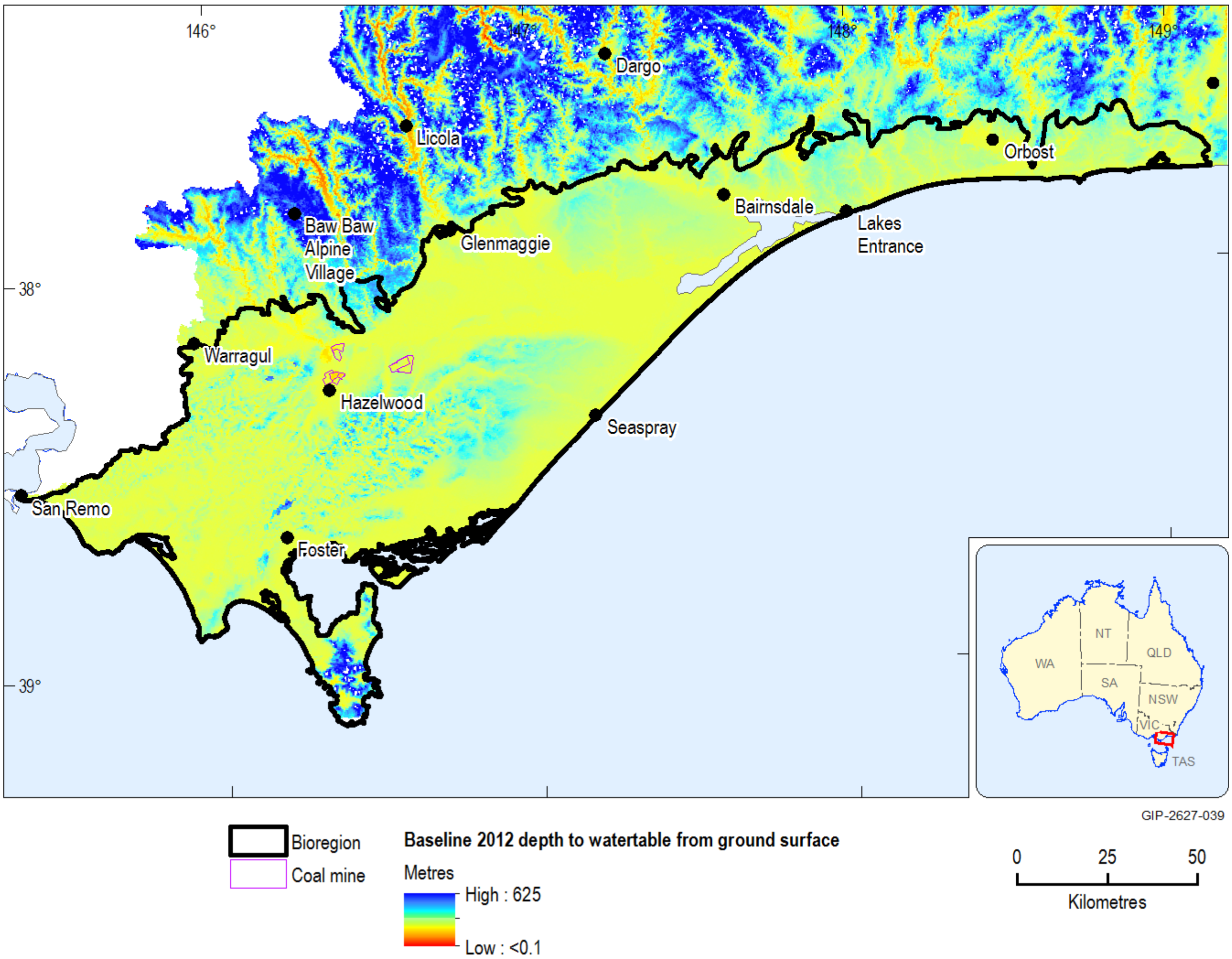


Figure 197 2012 baseline depth to water table (m) from ground surface

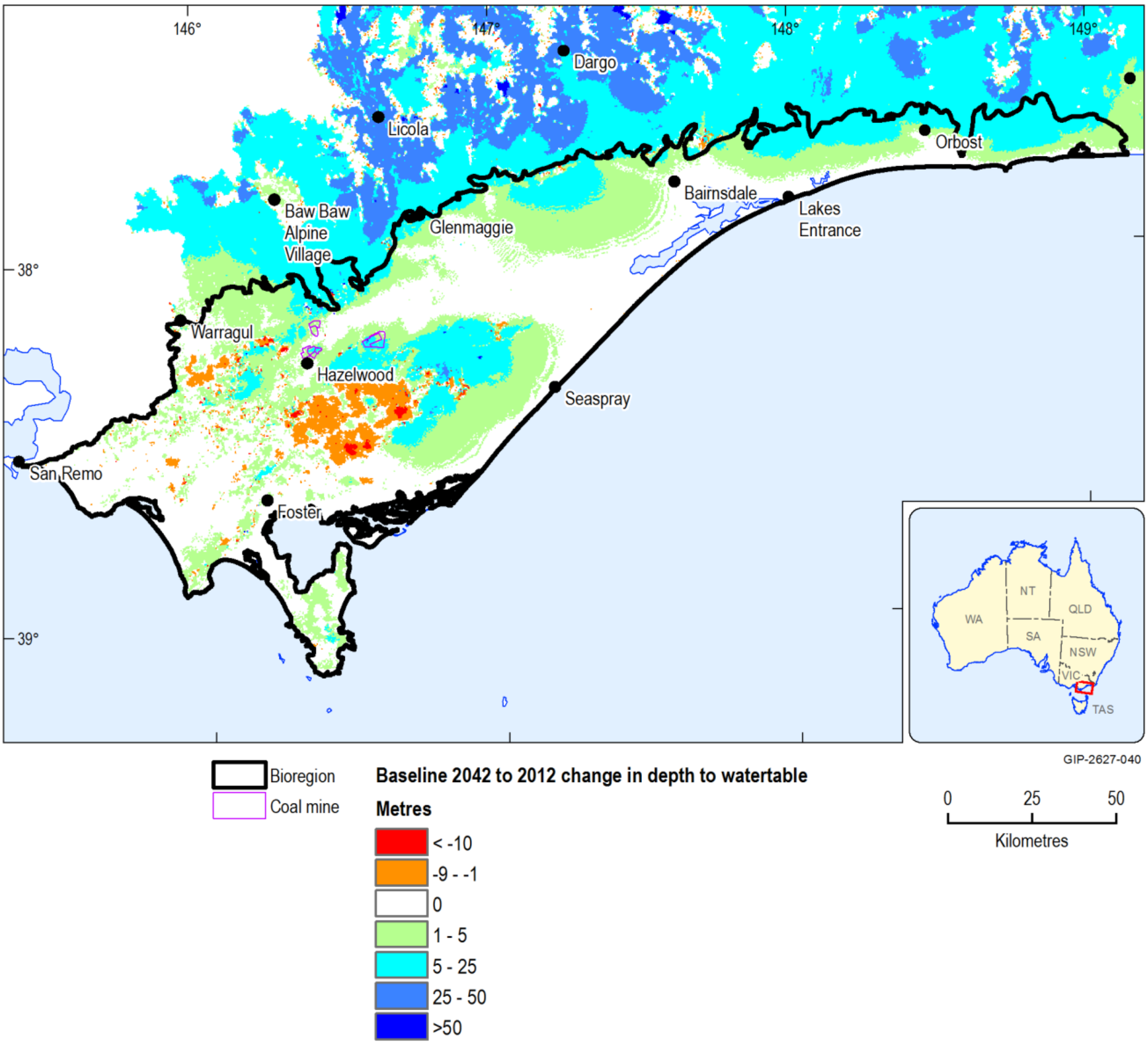


Figure 198 Change in depth to water table (m) at 2042 under baseline conditions relative to 2012 condition

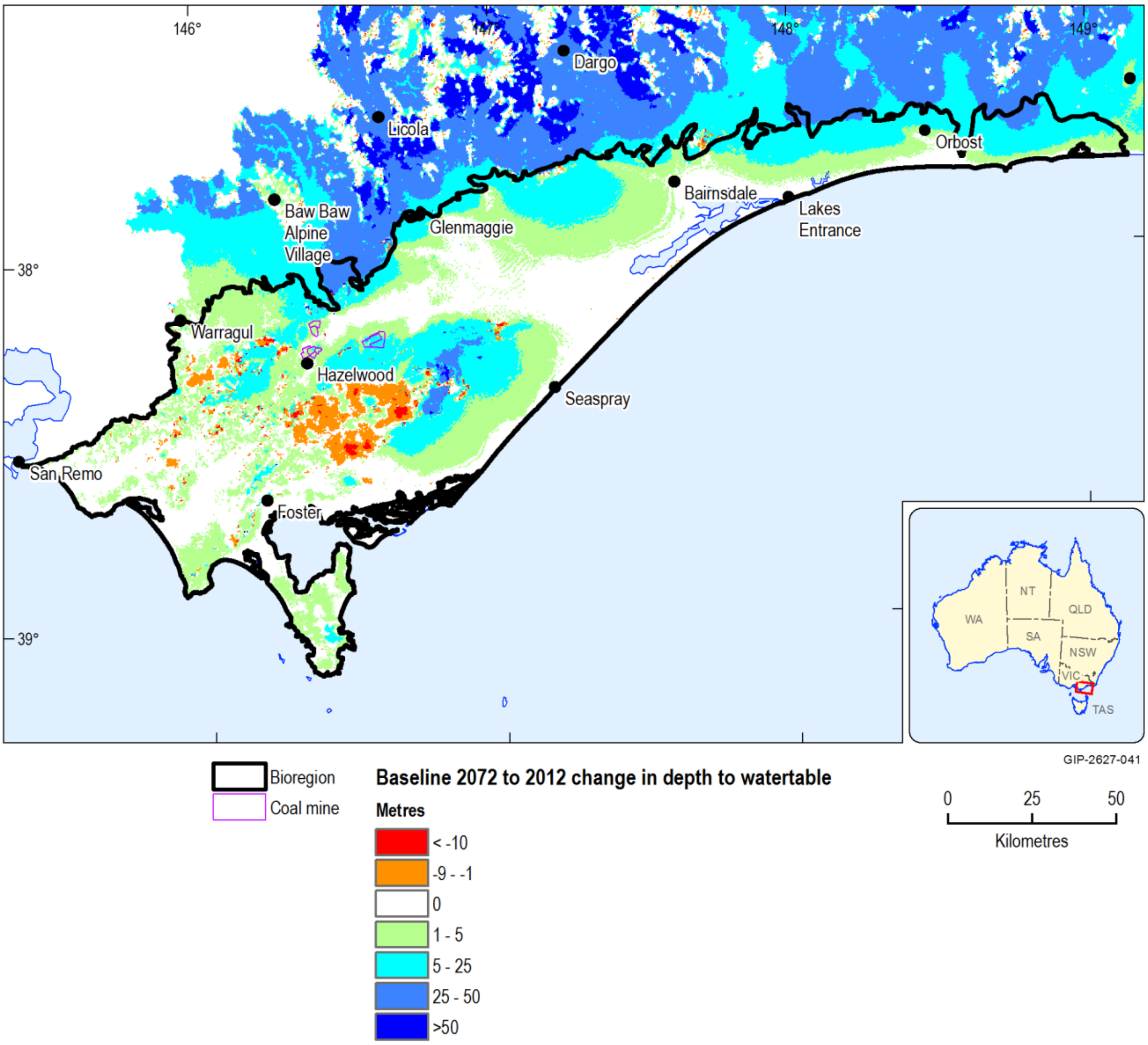


Figure 199 Change in depth to water table (m) at 2072 under baseline conditions relative to 2012 condition

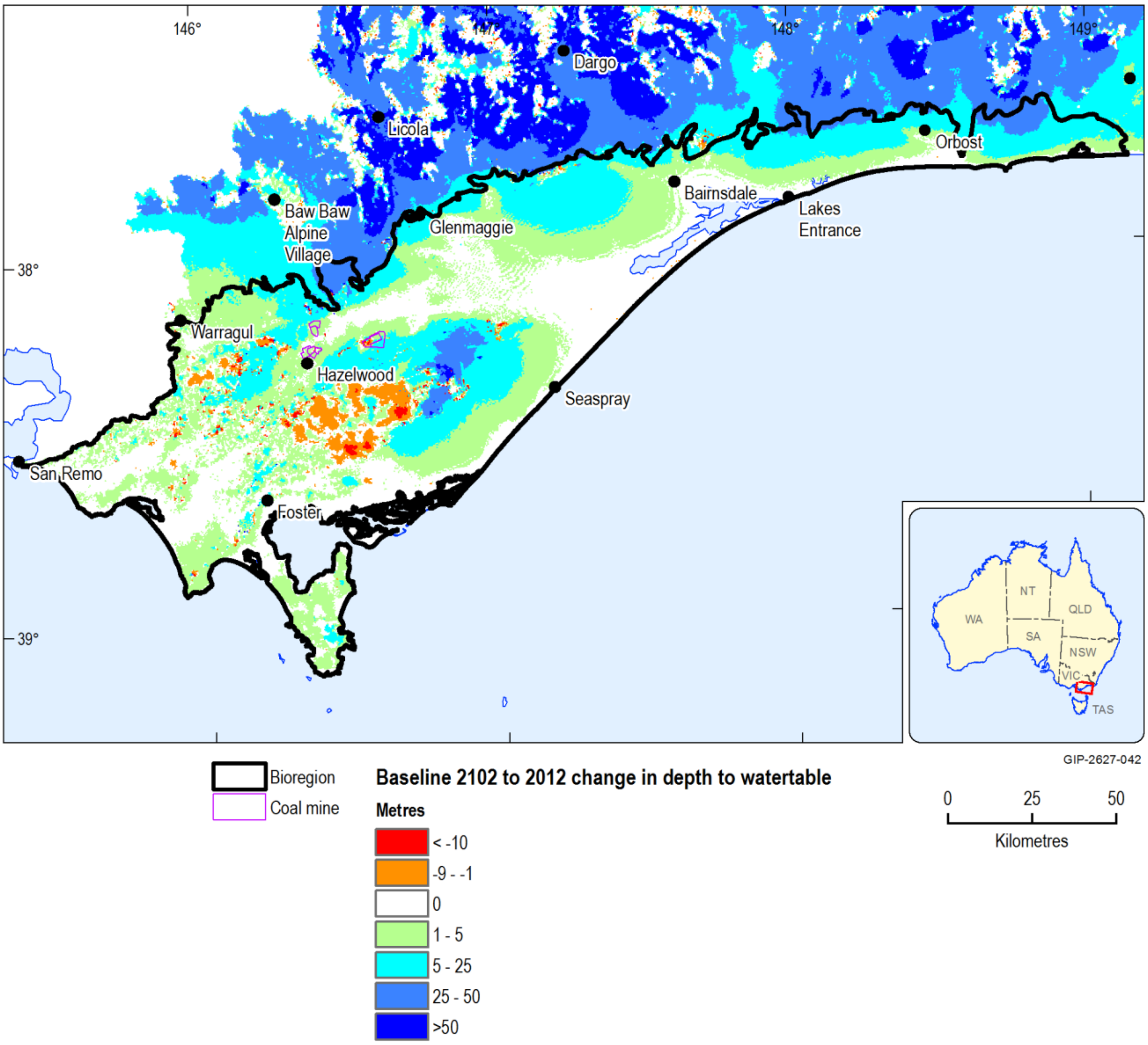


Figure 200 Change in depth to water table (m) at 2102 under baseline conditions relative to 2012 condition

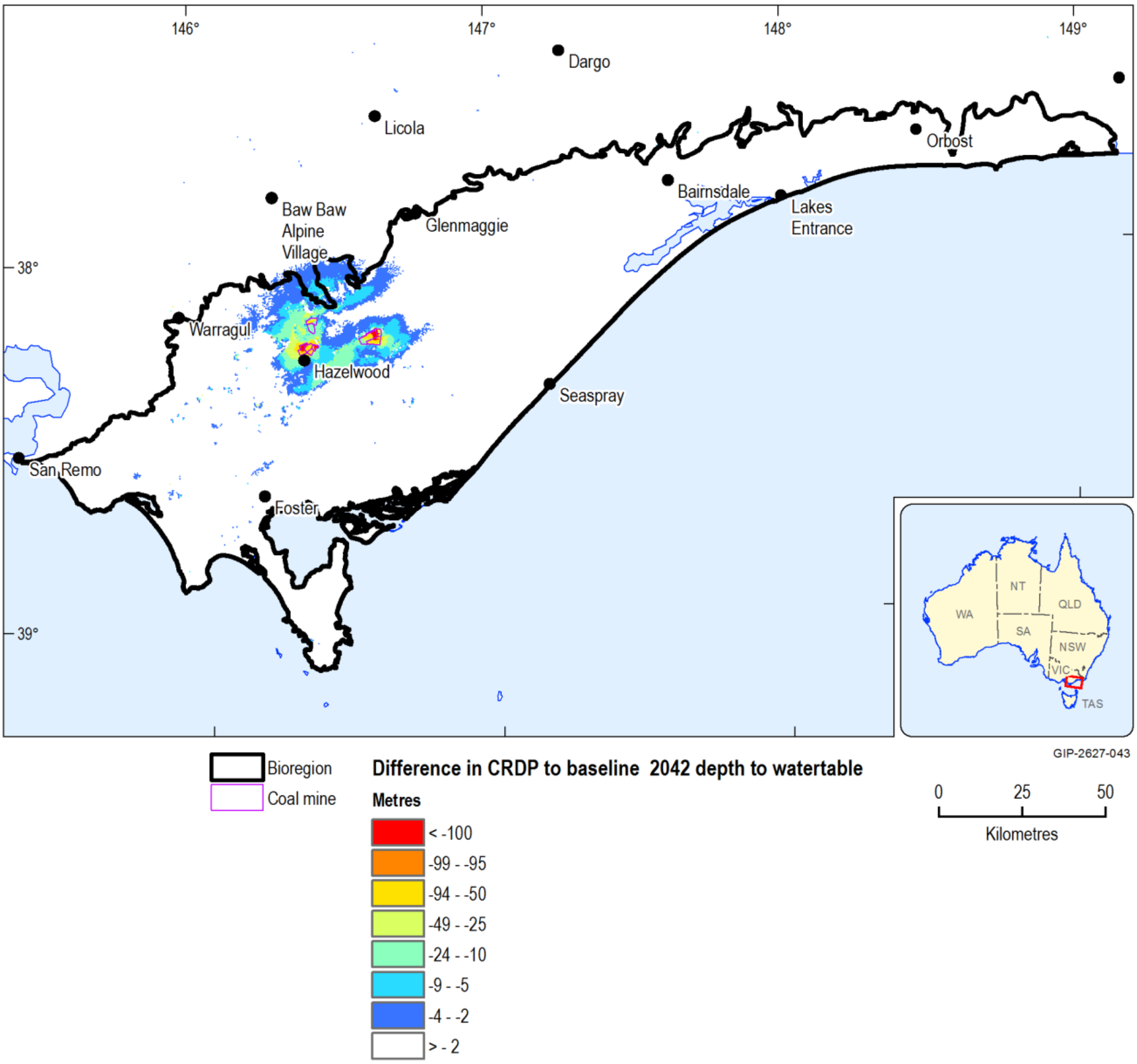


Figure 201 Change in depth to water table (m) at 2042 under CRDP conditions relative to 2042 baseline condition

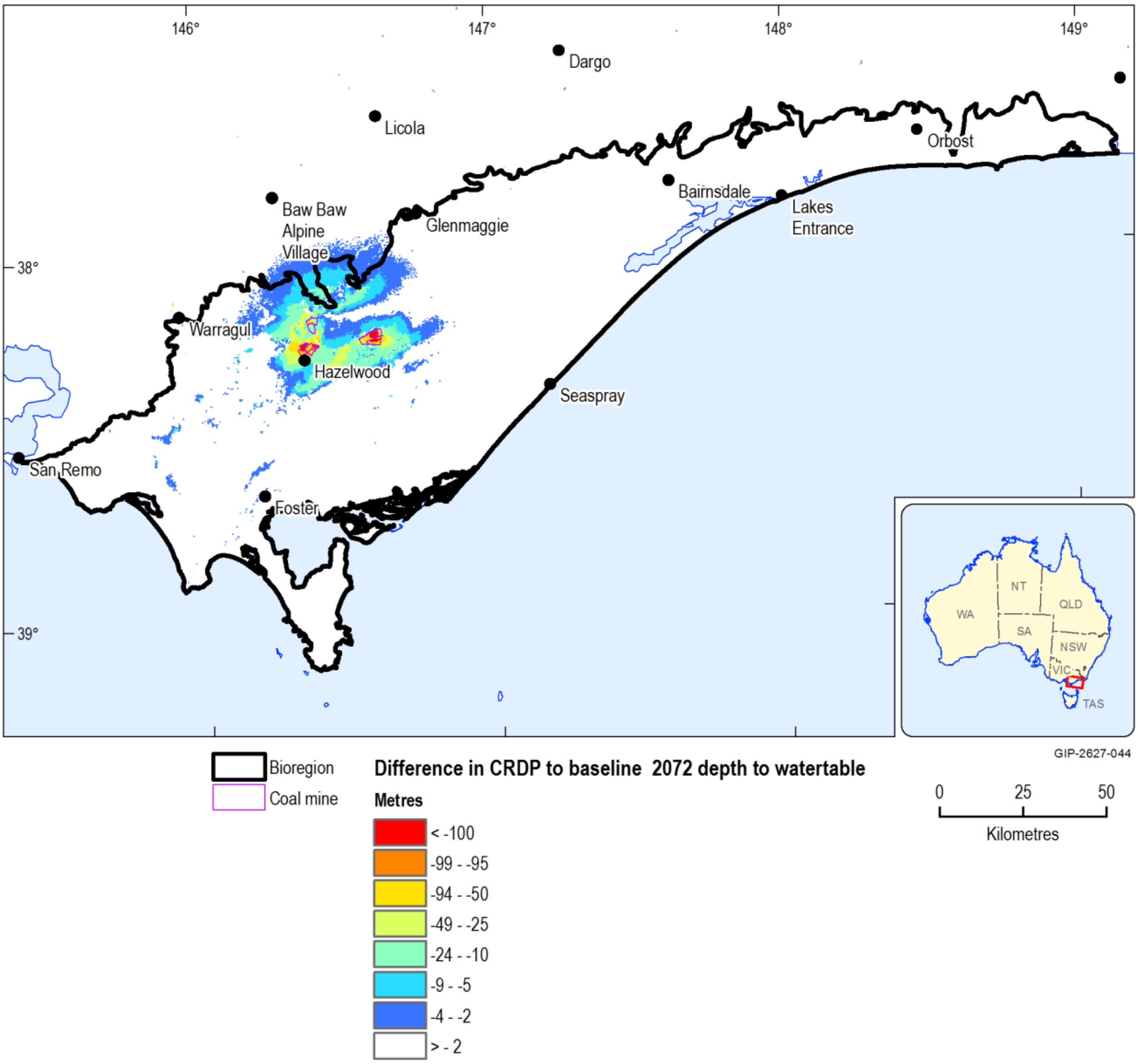


Figure 202 Change in depth to water table (m) at 2072 under CRDP conditions relative to 2072 baseline condition

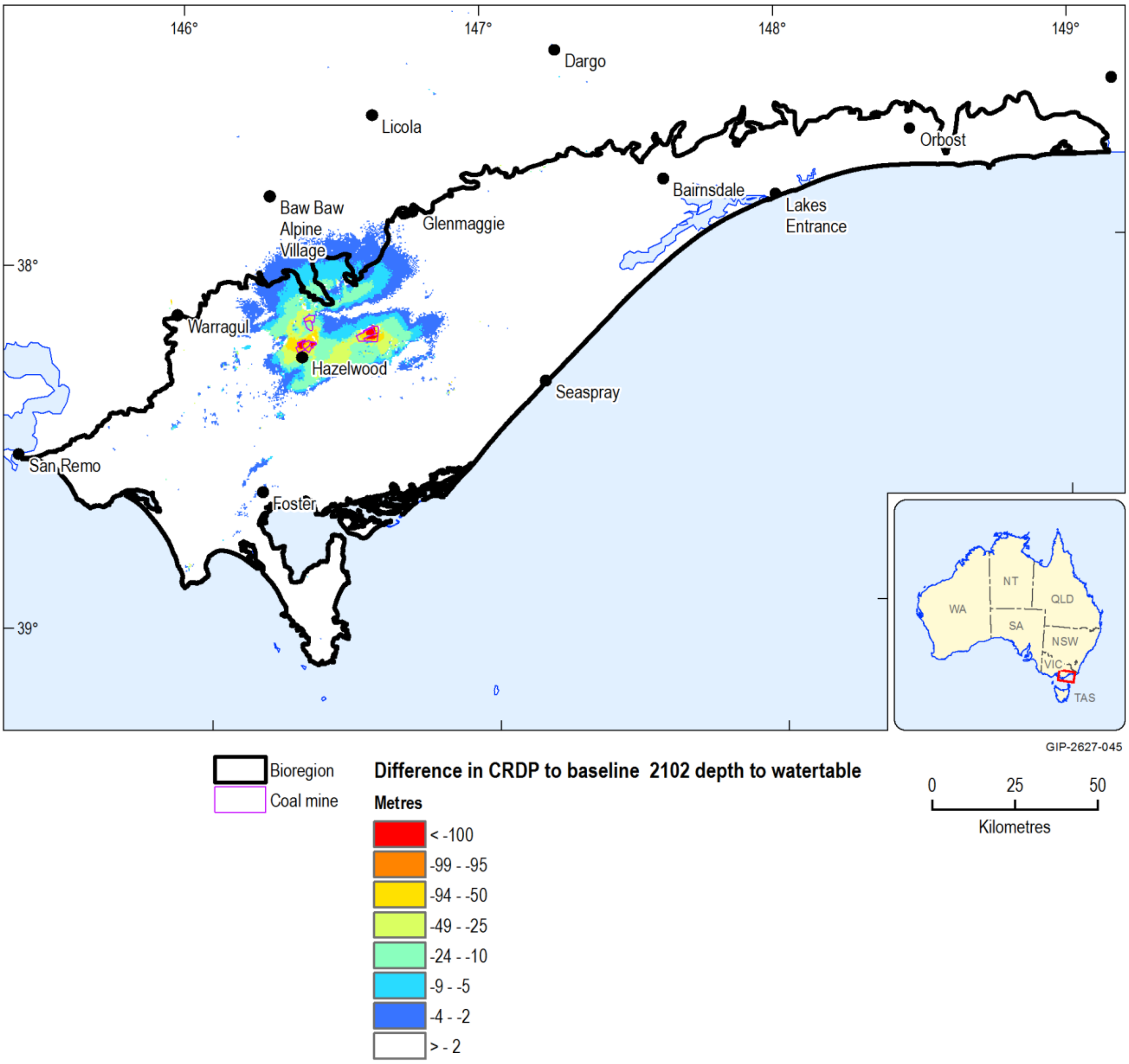


Figure 203 Change in depth to water table (m) at 2102 under CRDP conditions relative to 2102 baseline condition

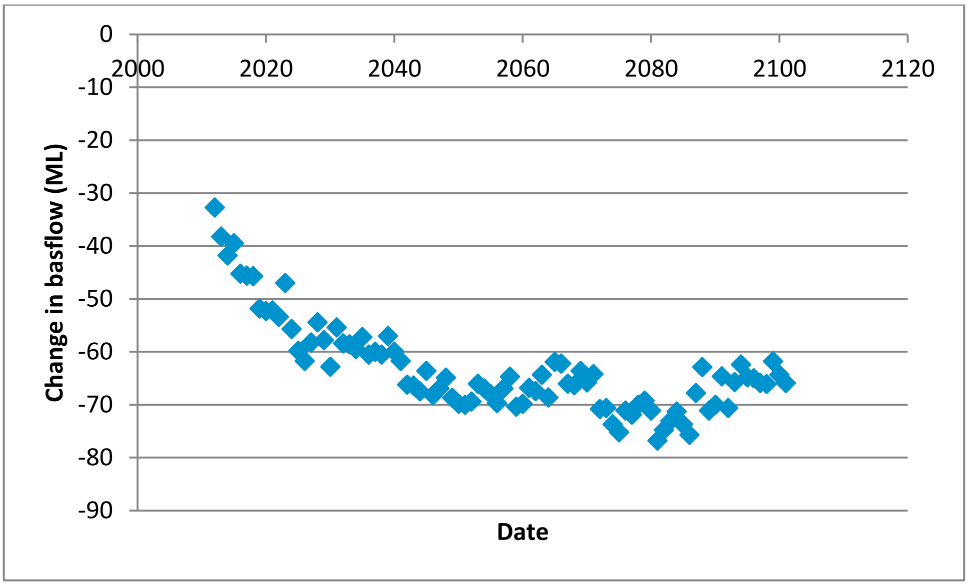


Figure 204 Change in predicted annual baseflow (ML/yr) to the Latrobe River relative to the baseline condition

2.6.2.8 Limitations

Summary

The distributed, multi-layered MODFLOW groundwater model described in this report was an enhancement of an existing model developed to investigate and understand the potential impacts of future onshore gas developments and to understand the possible impacts of a potential onshore natural gas industry on groundwater and surface waters within the Gippsland region.

In the immediate vicinity of the open-cut mines, the resolution of the model and the reliability of predictions is inferior to a local-scale model that accounts for local geological and hydrogeological detail.

The interpretation of predictions should account for model assumptions and limitations.

The key assumptions underpinning the development of the Gippsland region groundwater model are summarised in Table 29. These assumptions provide a foundation for the development of the model; while there is always some level of uncertainty the best available data has been used to limit predictive errors. It is likely that in some areas detailed hydrogeological processes have not been fully captured in the conceptualisation. Sub-catchment or site-specific investigations would be required to better define local variations and responses

Table 29 Key model assumptions

Assumption	Basis
There is no dual porosity.	Dual porosity models are only applicable to solute transport models and are not meaningful for flow models.
Groundwater concentration gradients are acknowledged to have some impact on groundwater heads but have not been explicitly included in the simulation.	Data limitations make inclusion into a dispersion-convective transient model problematic and would require significant additional computational resources and time.
Groundwater temperature gradients are acknowledged to have some impact on groundwater heads but have not been explicitly included in the simulation.	As for density driven.
Bores used in the model have been correctly assigned to aquifers.	Significant data cleansing work used to preparing data sets, however minor inaccuracies may exist.
The digital elevation model (DEM) has adequate vertical resolution to allow reasonable calibration of the model and represents the land surface topology over the entire domain.	Self-evident.
Land use change data is limited in availability and extent and has not been incorporated in this study.	Development scenarios based on existing land use.
The model cell size is adequate to meet project objectives.	Self-evident.

The developed groundwater model has been shown to broadly quantify groundwater flow and match historical hydrograph trends. The groundwater model is capable of predicting relative changes in hydraulic heads/water table and baseflow. The model is deemed appropriate to assess the potential regional cumulative impacts of gas developments and other groundwater users (including coal mines and offshore oil and gas extraction) on existing groundwater users and the environment against a baseline condition of the current development.

Key observations arising from this study are as follows:

- The need to recognise the assumptions and limitations associated with the model so as to ensure the appropriate use of the model and interpretation of model predictions. This groundwater model may be used to consider relative changes in the catchment water balance. However, the spatial accuracy of simulation results may not correlate well with gauged data due to the model construct and spatial resolution and therefore should be used with regards to these considerations.
- Caution should be exercised when using the solver option available in Groundwater Vistas by enabling the solution to continue if the convergence criteria are met for only the outer iterations without satisfying all convergence tolerances.

The following recommendations could improve the robustness and confidence of the groundwater model predictions as follows:

- Improve knowledge of groundwater abstraction across the region. This should extend to the compilation of basic information including the (1) location of pumping wells, (2) the groundwater volumes abstracted and (3) the nature of the aquifers from which abstractions are sourced.

- Translate the groundwater model into the recently developed UnStructured Grid (USG) version of MODFLOW, which would likely increase accuracy in the representation of processes in regions of steep hydraulic gradients (such as near mines, near connected surface features, adjacent to groundwater extraction points and in regions of stream/aquifer interaction) thereby improving groundwater predictions and water budget estimates.
- Further assess groundwater recharge estimates and associated hydrograph response would likely increase mass balance prediction accuracy.
- Incorporate temperature and density correction functions.
- Review model layers assigned to groundwater extraction bores.
- Review the attribution of the model layer representing the uppermost Strzelecki Formation. This suggestion is based on the analysis of spatial residual error presented in this report.

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