Australian Government

BIOREGIONAL ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE INFORMATION ASSOCIATED WITH COAL SEAM GAS AND LARGE COAL MINES

Context statement for the Gippsland Basin bioregion

Product 1.1 from the Gippsland Basin Bioregional Assessment

22 April 2015

A scientific collaboration between the Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia

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. The Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. 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/.

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Contents

Contributors to the Technical Programme ... x

Acknowledgements ... xii

Introduction ... 1

The Bioregional Assessment Programme ... 1
Methodologies ... 3
Technical products ... 4
About this technical product ... 7
References ... 7

1.1.1 Bioregion ... 10

1.1.1.1 Definition used ... 11

1.1.2 Geography ... 12

1.1.2.1 Physical geography ... 13
1.1.2.1.1 Physical overview ... 13
1.1.2.1.2 Physiographic regions ... 14
1.1.2.1.3 Soils and land capability ... 16
1.1.2.1.4 Land cover ... 19
1.1.2.2 Human geography ... 22
1.1.2.2.1 Population ... 22
1.1.2.2.2 Economic activity ... 25
1.1.2.2.3 Land use ... 26
1.1.2.2.4 Water storage ... 27
1.1.2.2.5 Indigenous heritage ... 28
1.1.2.3 Climate ... 28
1.1.2.3.1 Rainfall and aridity ... 29
1.1.2.3.2 Temperature ... 32
1.1.2.3.3 Future climate projections ... 33
References ... 34
Datasets ... 36

1.1.3 Geology ... 38

1.1.3.1 Geological structural framework ... 38
1.1.3.1.1 Definition of the basin, basin extent and regional geological context ... 38
1.1.3.1.2 Structure and sub-basins ... 40
1.1.3.2 Stratigraphy and rock type ... 44

1.1.3.2.1 Strzelecki Group 46
1.1.3.2.2 Latrobe Group 47
1.1.3.2.3 Seaspray Group 48
1.1.3.2.4 Sale Group 51
1.1.3.2.5 Quaternary 52
1.1.3.3 Basin history 52
1.1.3.4 Coal and hydrocarbons 54
1.1.3.4.1 Geological hazards 58
1.1.3.4.2 Conventional and unconventional hydrocarbons 58
1.1.3.4.3 Other reservoir resources 61
1.1.3.5 Potential basin connectivities 62
1.1.3.5.1 Underlying and adjacent basins and fractured bedrock aquifers 62
References 62
Datasets 66

1.1.4 Hydrogeology and groundwater quality 67

1.1.4.1 Groundwater systems 67
1.1.4.1.1 Bedrock aquifer system (Cretaceous and Ordovician to Carboniferous): Strzelecki Group and Paleozoic basement sediments and intrusives 71
1.1.4.1.2 Lower aquifer system (Eocene to Oligocene): Latrobe Group, basal coal units of the Morwell Formation sediments and volcanics 71
1.1.4.1.3 Middle aquifer system (Oligocene to Miocene): Latrobe Valley Group and Seaspray Group sediments 72
1.1.4.1.4 Upper aquifer system (Pleistocene to Holocene): Sale Group sediments 74
1.1.4.2 Groundwater quality 75
1.1.4.2.1 Spatial variability of groundwater quality 75
1.1.4.2.2 Temporal variability of groundwater quality 78
1.1.4.3 Groundwater flow 78
1.1.4.3.1 Gippsland Basin 79
1.1.4.3.2 Tarwin sub-basin 89
1.1.4.3.3 Moe Swamp sub-basin 90
1.1.4.3.4 Groundwater connectivity 90
1.1.4.4 Groundwater planning and use 92
1.1.4.5 Groundwater monitoring and assessment 96
1.1.4.5.1 Latrobe Valley regional monitoring network 97
1.1.4.5.2 Primary Industries Research Victoria (PIRVIC) boreholes 97
1.1.4.5.3 State Observation Bore Network 97
References 98
Datasets 100

1.1.5 Surface water hydrology and water quality 102

1.1.5.1 Surface water systems 103

1.1.5.1.1 South Gippsland River Region ... 106
1.1.5.1.2 Mitchell–Thomson River Region ... 108
1.1.5.1.3 Snowy River Region ... 110
1.1.5.1.4 East Gippsland River Region ... 112
1.1.5.2 Surface water quality ... 113
1.1.5.3 Surface water flow ... 115
References ... 119
Datasets ... 119

1.1.6 Surface water – groundwater interactions ... 121

1.1.6.1 Overview ... 121
1.1.6.2 South Gippsland ... 122
1.1.6.3 Mitchell–Thomson Rivers ... 123
1.1.6.4 Snowy River – East Gippsland ... 124
References ... 124

1.1.7 Ecology ... 126

1.1.7.1 Ecological systems ... 126
1.1.7.1.1 Water dependency ... 128
1.1.7.2 Terrestrial species and communities ... 132
1.1.7.2.1 Principal vegetation types and distribution patterns ... 132
1.1.7.2.2 Species and ecological communities of national significance ... 133
1.1.7.2.3 Species of regional significance ... 135
1.1.7.2.4 Threatening processes ... 136
1.1.7.3 Aquatic species and communities ... 143
1.1.7.3.1 Classification of aquatic habitats ... 143
1.1.7.3.2 Ramsar wetlands ... 145
1.1.7.3.3 Marine national parks ... 150
References ... 150
Datasets ... 151

Figures

Figure 1 Schematic diagram of the bioregional assessment methodology 2

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment 5

Figure 3 Gippsland Basin bioregion 10

Figure 4 Gippsland Basin bioregion showing river regions 11

Figure 5 Surface elevation of the Gippsland Basin bioregion 14

Figure 6 Physiographic regions of the Gippsland Basin bioregion 15

Figure 7 Classification of soils in the Gippsland Assessment area including location of potential coastal acid sulfate soils 16

Figure 8 Land cover of the Gippsland Basin bioregion 21

Figure 9 Population density of the Gippsland Basin bioregion 23

Figure 10 Land use of the Gippsland Basin bioregion 27

Figure 11 (a) Annual rainfall with smoothed rolling average and (b) annual rainfall divergence from the long-term mean for the Gippsland Basin bioregion 29

Figure 12 Mean annual rainfall across the Gippsland Basin bioregion 30

Figure 13 Mean monthly precipitation, potential evapotranspiration (PET) and ariditiy index for the Gippsland Basin bioregion. The black line indicates an aridity index of 1, where precipitation and PET are equal. 31

Figure 14 Aridity Index values across the Gippsland Basin bioregion 31

Figure 15 Monthly mean values of (a) precipitation,(b) potential evapotranspiration (PET), (c) maximum temperature (Tmax), (d) minimum temperature (Tmin), (e) vapour pressure deficit (VPD), (f) net radiation (Rn) and (g) wind speed for the Gippsland Basin bioregion 32

Figure 16 Annual trend by month of (a) precipitation, (b) potential evapotranspiration (PET), (c) maximum temperature (Tmax), (d) minimum temperature (Tmin), (e) vapour pressure deficit (VPD), (f) net radiation (Rn) and (g) wind speed for the Gippsland Basin bioregion, where P represents the statistical significance level. 33

Figure 17 Geology of the Gippsland Basin bioregion including faults and structural elements. Locations of cross-sections A1–A2 and B1–B2 are delineated 40

Figure 18 Schematic geological cross-section (A1–A2) of the Gippsland Basin showing the major geological unit groupings 43

Figure 19 Schematic geological cross-section (B1–B2) of the Gippsland Basin showing the major geological unit groupings 44

Figure 20 Gippsland Basin onshore stratigraphy 45

Figure 21 Distribution of coal fields and resources, oil and gas fields of the Gippsland Basin 55

Figure 22 Hydrostratigraphy of the Gippsland Basin, and Moe Swamp and Tarwin sub-basins 69

Figure 23 Groundwater salinity (total dissolved solids (mg/L)) in the Gippsland Basin bioregion ... 76

Figure 24 Regional watertable, Gippsland Basin bioregion, (a) 1980 and (b) 2012. Note that this surface is based on preliminary modelling and will be subject to change as modelling progresses for the purpose of the bioregional assessment 80

Figure 25 Potentiometric surface, Boisdale Formation (an aquifer of the Middle Aquifer System), (a) 1980 and (b) 2012. Note that this surface is based on preliminary modelling and will be subject to change as modelling progresses for the purpose of the bioregional assessment 81

Figure 26 Potentiometric surface, upper Latrobe Group (aquifers of the Lower Aquifer System), (a) 1980 and (b) 2012. Note that this surface is based on preliminary modelling and will be subject to change as modelling progresses for the purpose of the bioregional assessment 82

Figure 27 Basement aquifer system representative hydrograph. Elevation is in Relative Water Level (RWL) in mAHD 86

Figure 28 Lower aquifer system representative hydrographs. Elevation is in Relative Water Level (RWL) in mAHD 87

Figure 29 Middle aquifer system representative hydrographs. Elevation is in Relative Water Level (RWL) in mAHD 88

Figure 30 Upper aquifer system representative hydrographs. Elevation is in Relative Water Level (RWL) in mAHD 89

Figure 31 Distribution of aquifers and aquitards of the Gippsland Basin bioregion for (a) upper, (b) middle and (c) lower aquifer systems 91

Figure 32 Groundwater management areas in the Gippsland Basin bioregion. Groundwater management areas cover most of the bioregion area 96

Figure 33 Location of the Gippsland Basin bioregion, town centres and major watercourses, and associated nearby Geofabric river regions 104

Figure 34 Schematic representation of major watercourses and their inter-linkages with each other in the Gippsland Basin bioregion 105

Figure 35 South Gippsland River Region showing major rivers, water assets, lands subject to inundation and location of mining development for the Gippsland Basin bioregion 107

Figure 36 Mitchell–Thomson River Region showing major rivers, water assets, lands subject to inundation and location of mining development for the Gippsland Basin bioregion 109

Figure 37 Snowy River Region showing major rivers, water assets, lands subject to inundation and location of mining development for the Gippsland Basin bioregion....................................... 111

Figure 38 East Gippsland River Region showing major rivers, water assets and lands subject to inundation for the Gippsland Basin bioregion.. 113

Figure 39 Flow distribution at Meeniyan on the Tarwin River in South Gippsland River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:227202)............................ 116

Figure 40 Flow distribution at Glenaladale on the Mitchell River in Mitchell-Thomson River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:224203) 117

Figure 41 Flow distribution at Sardine Creek on the Brodribb River in Snowy River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:222202) 117

Figure 42 Flow distribution at Princes Highway on the Bemm River in East Gippsland River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:221212) 118

Figure 43 Interim Biogeographic Regionalisation of Australia bioregions (IBRA), wetlands and rivers within the Gippsland Basin bioregion 129

Figure 44 National Vegetation Information System (NVIS) major vegetation subgroups............... 133

Figure 45 Distribution of ecological vegetation communities with Endangered and Vulnerable conservation status within the Gippsland Basin bioregion 136

Tables

Table 1 Methodologies and associated technical products listed in Table 2 3

Table 2 Technical products being delivered as part of the Gippsland Basin Bioregional Assessment 6

Table 3 Characteristics of the physiographic regions of the Gippsland Basin 15

Table 4 Area and percentage of the Gippsland Basin bioregion by soil type 17

Table 5 Area and percentage of the Gippsland Basin bioregion by land cover class 20

Table 6 Main population centres of the Gippsland Basin bioregion and their population change from 2001 to 2011 24

Table 7 Population growth by local government area between 2011 and 2012 for the Gippsland Basin bioregion.. 25

Table 8 Area and percentage of the Gippsland Basin bioregion covered by land use category....... 26

Table 9 Water storages of the Gippsland Basin bioregion 28

Table 10 Predicted degree of change to rainfall for the catchments in the Gippsland Basin bioregion under two global warming scenarios 34

Table 11 Predicted degree of change to runoff for the catchments in the Gippsland Basin bioregion under two global warming scenarios 34

Table 12 Brown coal fields of the Gippsland Basin 56

Table 13 Gippsland Basin oil and gas resources in units of Petajoules (PJ)..................................... 59

Table 14 Gippsland Basin petroleum system... 60

Table 15 Guide to hydrostratigraphy indicating relationships between the Victorian Aquifer Framework naming conventions and the hydrogeological units used in the Bioregional Assessment 70

Table 16 Water supply protection areas (WSPA) and groundwater management areas (GMU) within the Gippsland Basin bioregion 94

Table 17 State Observation Bore Network monitoring bores in the Gippsland Basin[1].................... 98

Table 18 List of stream gauges in the Gippsland Basin bioregion located in four river basins that are part of Gippsland Basin bioregion hydrological study.. 115

Table 19 Surface water availability and usage for the river regions in the Gippsland Basin bioregion 118

Table 20 National Vegetation Information System (NVIS Version 4.1) major vegetation subgroups in the Gippsland Basin bioregion 130

Table 21 Australian Land Use and Management land use classes in the Gippsland Basin bioregion 132

Table 22 Species and ecological communities within the Gippsland Basin bioregion listed as threatened nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act). State-listed threatened species under Victoria's *Flora and Fauna Guarantee Act 1988* (the FFG Act) are indicated with a box 137

Table 23 Nationally important wetlands in the Gippsland Basin bioregion listed in *A Directory of Important Wetlands in Australia* (Department of the Environment, 2014c) 143

Table 24 Area of wetlands in the Gippsland Basin bioregion under four classes, incorporating wetland description 144

Table 25 Migratory shorebirds within Corner Inlet Ramsar site that are listed as EPBC Act Migratory species. Many species are also listed under bilateral agreements as indicated with a box 148

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- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment), this group comprises officials from the New South Wales, Queensland, South Australian and Victorian governments.

Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments.

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA will be different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions:

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion
- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in a later section) will progressively be delivered throughout the Programme.

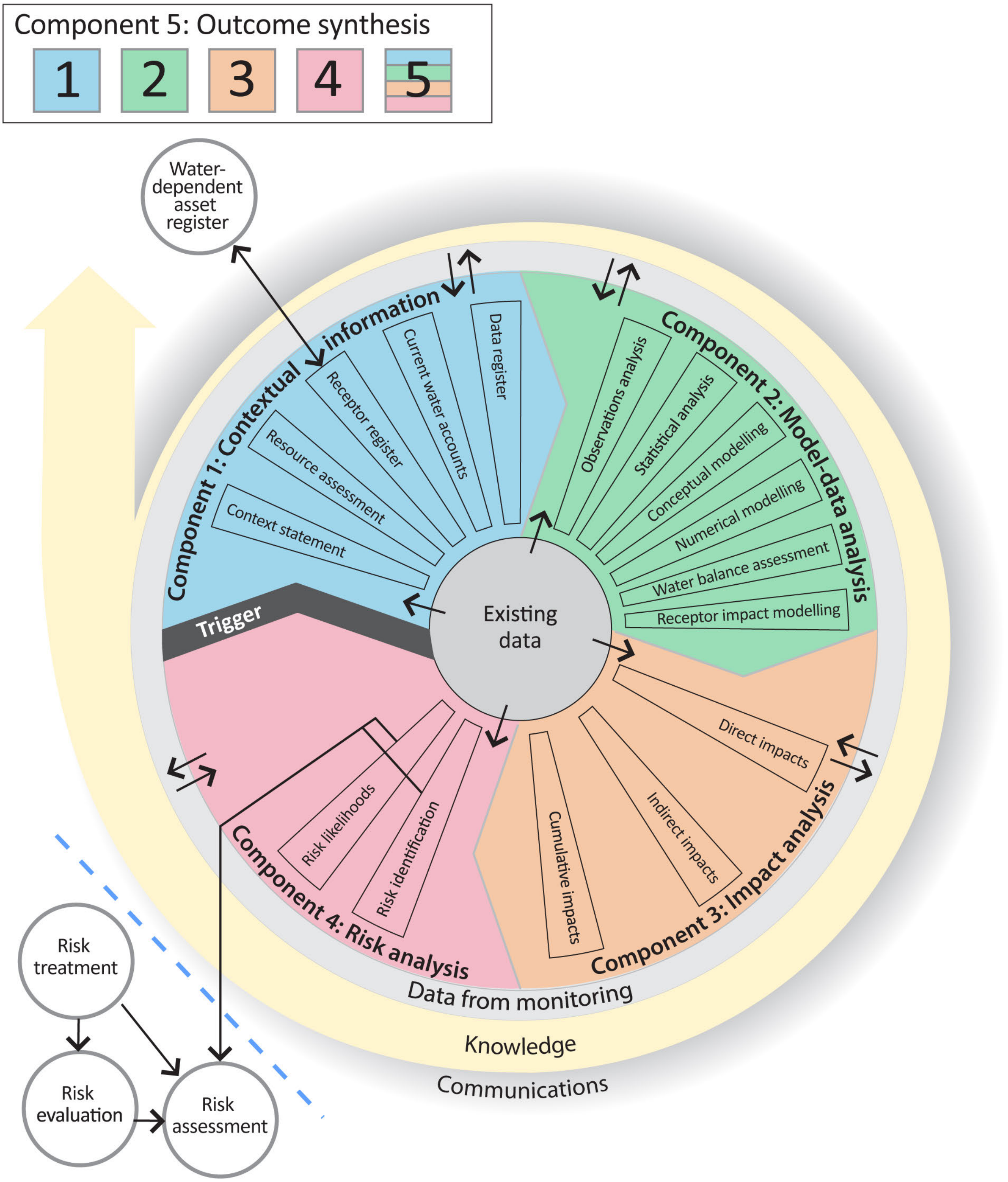


Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the *Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources* (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at http://www.bioregionalassessments.gov.au. Submethodologies might be added in the future.

Technical products

The outputs of the BAs include a suite of technical products variously presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential direct, indirect and cumulative impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are available to the public, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified in the BA methodology. Figure 2 shows the information flow within a BA. Table 2 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red rectangles in both Figure 2 and Table 2 indicate the information included in this technical product.

This technical product is delivered as a report (PDF). Additional material is also provided, as specified by the BA methodology:

- all unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- the workflow, comprising a record of all decision points along the pathway towards completion of the BA, gaps in data and modelling capability, and provenance of data.

The PDF of this technical product, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

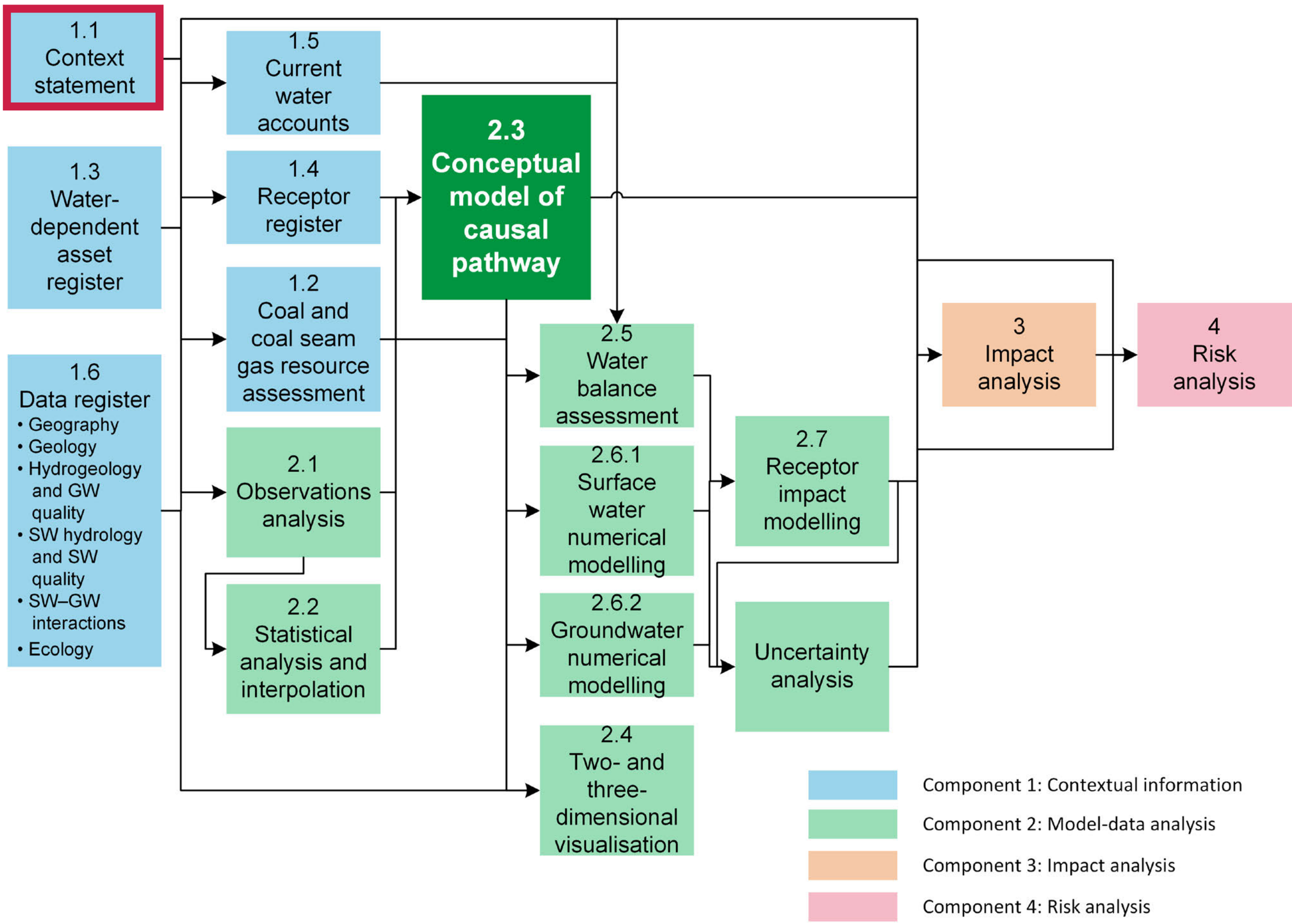


Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red rectangle indicates the information included in this technical product.

Table 2 Technical products being delivered as part of the Gippsland Basin Bioregional Assessment

For each subregion in the Gippsland Basin Bioregional Assessment, technical products will be delivered as data, summaries and reports (PDFs) as indicated by ■ in the last column of Table 2. The red rectangle indicates the information covered in this technical product. A suite of other technical and communication products – such as maps, registers and factsheets – will also be developed through the bioregional assessments.

Component	Product code	Information	Section in the BA methodology[a]	Report
Component 1: Contextual information for the Gippsland Basin bioregion	1.1	Context statement	2.5.1.1, 3.2	■
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	■
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	■
	1.4	Description of the receptor register	2.5.1.4, 3.5	■
	1.5	Current water accounts and water quality	2.5.1.5	■
	1.6	Data register	2.5.1.6	
Component 2: Model-data analysis for the Gippsland Basin bioregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	■
	2.3	Conceptual modelling	2.5.2.3, 4.3	■
	2.4	Two- and three-dimensional representations	4.2	b
	2.5	Water balance assessment	2.5.2.4	■
	2.6.1	Surface water numerical modelling	4.4	■
	2.6.2	Groundwater numerical modelling	4.4	■
	2.7	Receptor impact modelling	2.5.2.6, 4.5	■
Component 3: Impact analysis for the Gippsland Basin bioregion	3	Impact analysis	5.2.1	■
Component 4: Risk analysis for the Gippsland Basin bioregion	4	Risk analysis	2.5.4, 5.3	■
Component 5: Outcome synthesis for the Gippsland Basin	5	Outcome synthesis	2.5.5	■

[a]Barrett et al. (2013)
[b]The two- and three-dimensional representations will be delivered in products such as 2.3, 2.6.1 and 2.6.2.

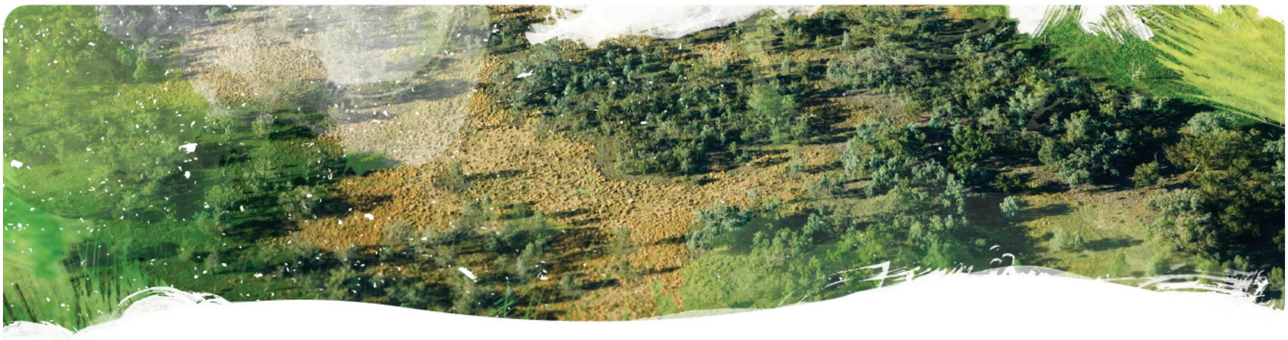
About this technical product

The following notes are relevant only for this technical product.

- The context statement is a collation of existing information and thus in some cases figures are reproduced from other sources. These figures were not redrawn for consistency (with respect to 'look and feel' as well as content), and the resolution and quality reflects that found in the source.
- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151° East for the Gippsland Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Contact bioregionalassessments@bom.gov.au to access metadata (including copyright, attribution and licensing information) for all datasets cited or used to make figures in this product. At a later date, this information, as well as all unencumbered datasets, will be published online.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 17 August 2015, http://www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf.



1.1 Context statement for the Gippsland Basin bioregion

The context statement brings together what is currently known about the geography, ecology, hydrology, geology and hydrogeology of a subregion or bioregion. It provides baseline information that is relevant to understanding the regional context of water resources and water-dependent assets, which might be impacted by coal and coal seam gas development. Information is collated that is relevant to interpret the impact analysis, risk analysis and outcomes of the bioregional assessment.

The context statement includes materially relevant characteristics of a subregion or bioregion that are needed to adequately interpret output from ecological, surface water and groundwater datasets and models, and from this develop improved knowledge of whole-of-system functioning.

No new analysis or modelling is presented in the context statement; rather it draws on existing information. Thus, some figures are reproduced from other sources and the look and feel of these external figures is not consistent with those produced in the bioregional assessment. Likewise, results from different sources may use different methods or inconsistent units.

1.1.1 Bioregion

The Gippsland Basin bioregion is located in south-east Victoria (Figure 3). It covers an area of approximately 14,636 km². This bioregion is defined by the onshore extent of the geological Gippsland Basin and includes the brown coal mines of the Latrobe Valley in the vicinity of Morwell and Traralgon. The Gippsland Basin Bioregional Assessment is focused on the risk and impacts to water dependent assets potentially arising from onshore resources of coal seam gas and coal mining, which subsequently constrains the bioregion to the onshore reaches of the geological Gippsland Basin. Approximately 70% of the geological Gippsland Basin occurs offshore.

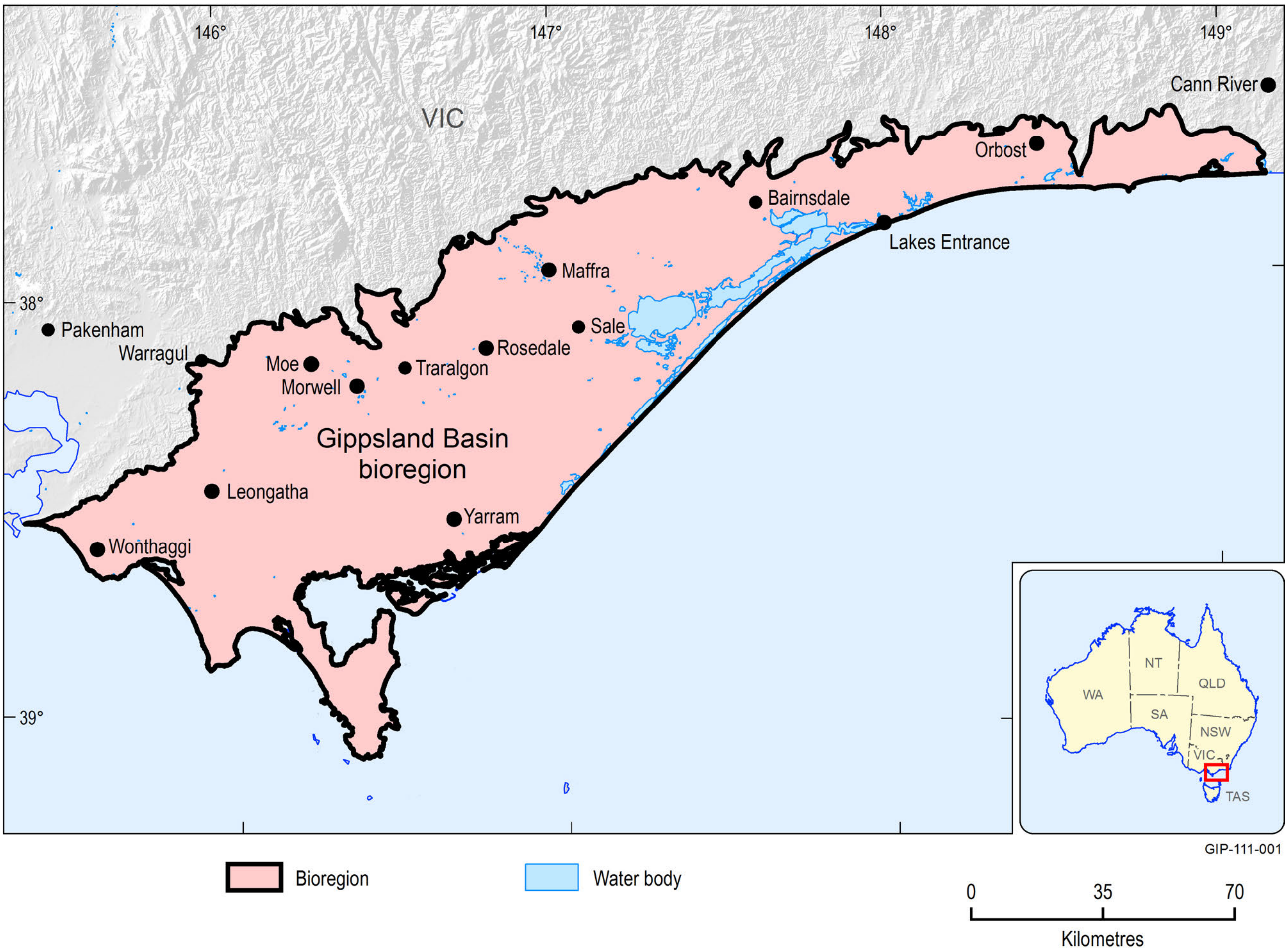


Figure 3 Gippsland Basin bioregion

Key river basins in the Gippsland Basin bioregion include the South Gippsland, La Trobe, Thomson, Mitchell, Tambo and Nicholson, Snowy, and parts of East Gippsland river basins (Figure 4). All key river basins drain seaward, many via Ramsar-listed wetlands including Gippsland Lakes and Corner Inlet.

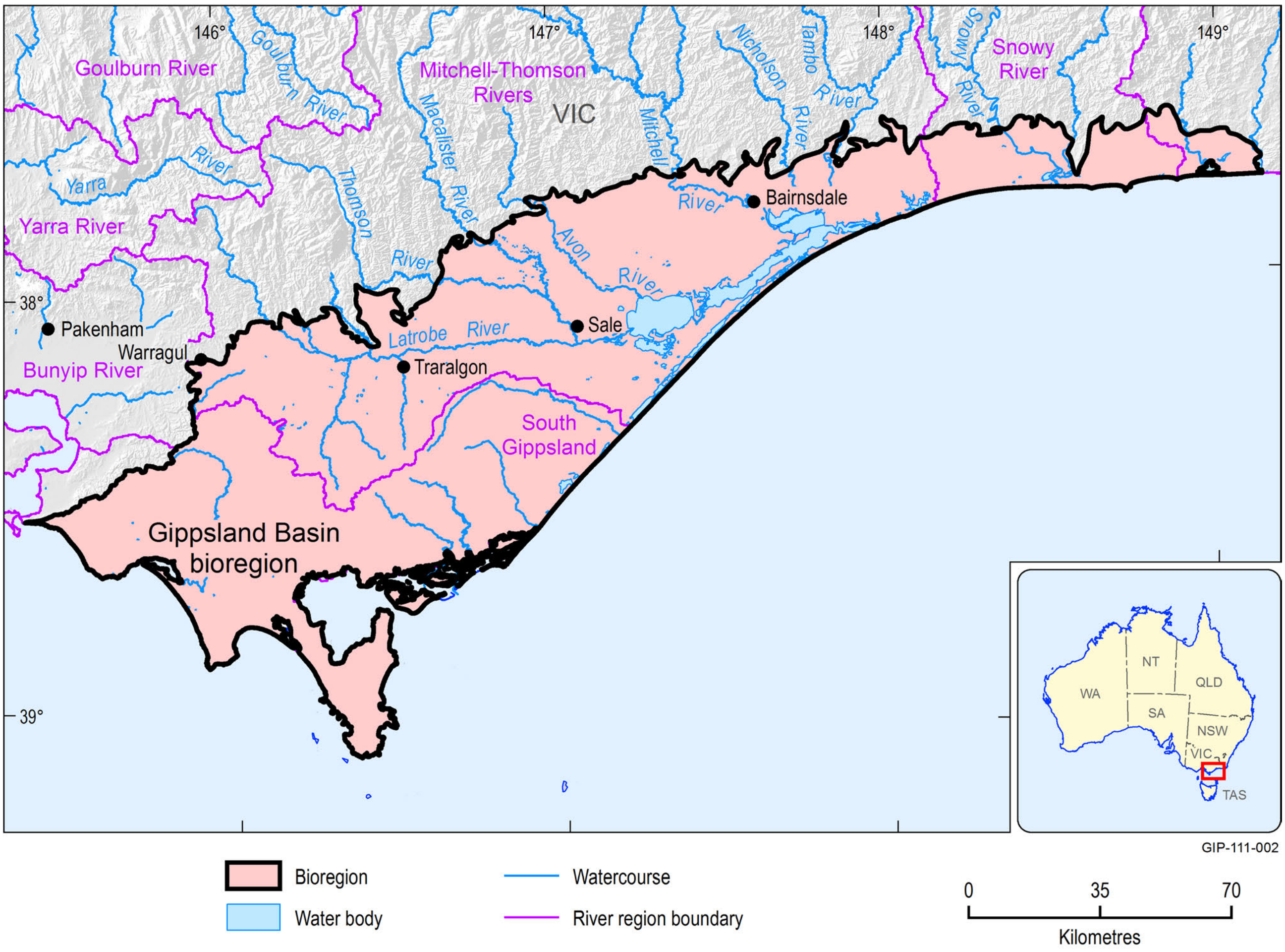


Figure 4 Gippsland Basin bioregion showing river regions

1.1.1.1 Definition used

The Gippsland Basin bioregion considered in this assessment includes key parts of the geological Gippsland Basin which contain major coal resources. The bioregion's northern boundary follows the surface geology expressions of the Haunted Hill and Sale Group aquifers which overlie and conceal the coal-bearing formations of the Gippsland Basin. It also includes the Gippsland Lakes in the south-east.

The Gippsland Basin bioregion includes parts of the two natural resource management regions: East Gippsland Catchment and West Gippsland Catchment. The West Gippsland Catchment Management Authority contains the Avon River Basin and all river basins further west within the bioregion. The East Gippsland Catchment Management Authority contains the Mitchell River Basin and all river basins further east within the bioregion.

1.1.2 Geography

Summary

The Gippsland Basin bioregion is situated in south-eastern Victoria and covers an area of approximately 14,636 km^2. The bioregion includes the area between the foothills of the Great Dividing Range to the north, and the Bass Strait coast to the south, Warragul to the west, and the Cann River to the east. The elevation of the bioregion ranges from sea level to 750 m at Mount Tassie within the Strzelecki Ranges.

The soil types of the Gippsland Basin bioregion generally align with the broad landscape features, the underlying geology and physical location. Eleven soils types are represented across the bioregion, with over 50% of the area covered by Sodosols and Dermosols. Much of the soil in the Gippsland Basin bioregion is nutrient depleted due its age and natural weathering. Additionally, soil has been further depleted in some areas from extensive grazing and agriculture over a long period of time causing compaction and erosion of the fertile upper soil horizon. Despite this, the use of fertilisers and irrigation has enabled the region to become highly productive for crops, farming and forestry.

The economy of Gippsland is primarily based on agriculture, forestry, dairy and mining with a gross regional product estimated at $13.26 billion. The Gippsland region contributes over 20% of national milk production. In particular, the Macalister Irrigation District is a key dairy, agriculture and forestry area and covers approximately 530 km^2 between Sale and Lake Glenmaggie following the Macalister and Thomson river valleys.

Approximately 90% of Victorian power is generated from three power stations within the bioregion at Yallourn, Hazelwood and Loy Yang, with coal sourced from the Latrobe Valley. It is estimated that 430 Bt of brown coal remain in situ in the Latrobe Valley, with 33 Bt of economic resource. In addition, conventional oil and gas from the Gippsland Basin contributes approximately 20% of Australia’s production.

There are four major water storage locations within the Gippsland Basin bioregion: Lake Glenmaggie, Cowwarr Weir, Blue Rock Dam and Lake Narracan. The Thomson Reservoir is situated north of the bioregion and is the largest water storage in Melbourne’s water supply.

The bioregion covers six Victorian local government areas, although none are fully included within the bioregion. The overall population of the Gippsland Basin bioregion has been estimated at 203,445 based on the population counts of the 2011 Australian Bureau of Statistics census. The population is dispersed throughout the region, with over 40% of the population residing in towns with less than 1000 people. Although there are no major cities falling within the Assessment area, there are six population centres in the bioregion which have a population of over 10,000.

The climate across the Gippsland Basin bioregion is temperate and is influenced by the geography, topography, elevation and distance from the coast. The mean long-term annual precipitation across the bioregion is 835 mm, although this is variable across the bioregion. The Gippsland plains receive on average 500 to 700 mm rainfall annually, with the higher

peaks of the Strzelecki Ranges and Wilsons Promontory receiving up to 2000 m rainfall annually. The region experiences summers with mean maximum temperatures around 24°C and mean minimums of around 13°C. Winter temperatures range from 5°C to 14°C.

Projected future climate outcomes for the catchments in the bioregion have been determined through the South Eastern Australian Climate Initiative study. The study performed modelling analysis on 15 global climate models and daily rainfall and areal potential evapotranspiration statistics from 1895 to 2008 under scenarios of 1 and 2 degrees of warming. In all warming scenarios it is predicted that the annual rainfall and runoff will reduce compared to the historical mean.

1.1.2.1 Physical geography

1.1.2.1.1 Physical overview

The Gippsland Basin bioregion is situated in south-eastern Victoria and covers an area of approximately 14,636 km^2. The bioregion includes the area between the foothills of the Great Dividing Range to the north, and the Bass Strait coast to the south, Warragul to the west, and the Cann River to the east. Although the Gippsland Basin extends into Bass Strait, the Assessment area only covers the onshore part of the basin. Figure 5 shows the topography of the area and the location of the major rivers.

The Strzelecki Ranges make up the central-west section of the bioregion, reaching a maximum elevation of 750 m at Mount Tassie. The ranges are divided from the Victorian Alps to the north by the Latrobe Valley. To the north-east of the ranges the elevation decreases to the lower-lying Gippsland plains, covering the area between Traralgon and Bairnsdale. This area includes floodplains and river valleys leading to the ecologically-sensitive Gippsland Lakes at the northern end of the Gippsland plains. In the eastern section of the bioregion the low-lying plains give way to state forest and dairy interspersed by the towns of Orbost and Marlo. Wilsons Promontory makes up the southern tip of the bioregion and has numerous peaks including Mount Latrobe (754 m), Mount Wilson (705 m), and Mount Ramsay (679 m).

The bioregion covers parts of four river basins: South Gippsland, Mitchell-Thomson Rivers, Snowy River and East Gippsland. The majority of the rivers in the bioregion originate in the Great Dividing Range and flow through the region to the Gippsland Lakes and coast. These include the Avon, Bemm, Brodribb, Latrobe, Macalister, Mitchell, Nicholson, Snowy, Tambo, and Thomson rivers. In addition the Albert River, Tarra River, Bruthern Creek and Merriman Creek originate in the Strzelecki Ranges. Figure 30 in Section 1.1.5 shows the location of the major rivers and catchment areas in the bioregion.

The Assessment area covers a number of ecologically significant sites, including Ninety Mile Beach, Corner Inlet, Wilsons Promontory and the Gippsland Lakes. Of these the Gippsland Lakes and Corner Inlet are listed as wetlands of international significance under the Ramsar convention.

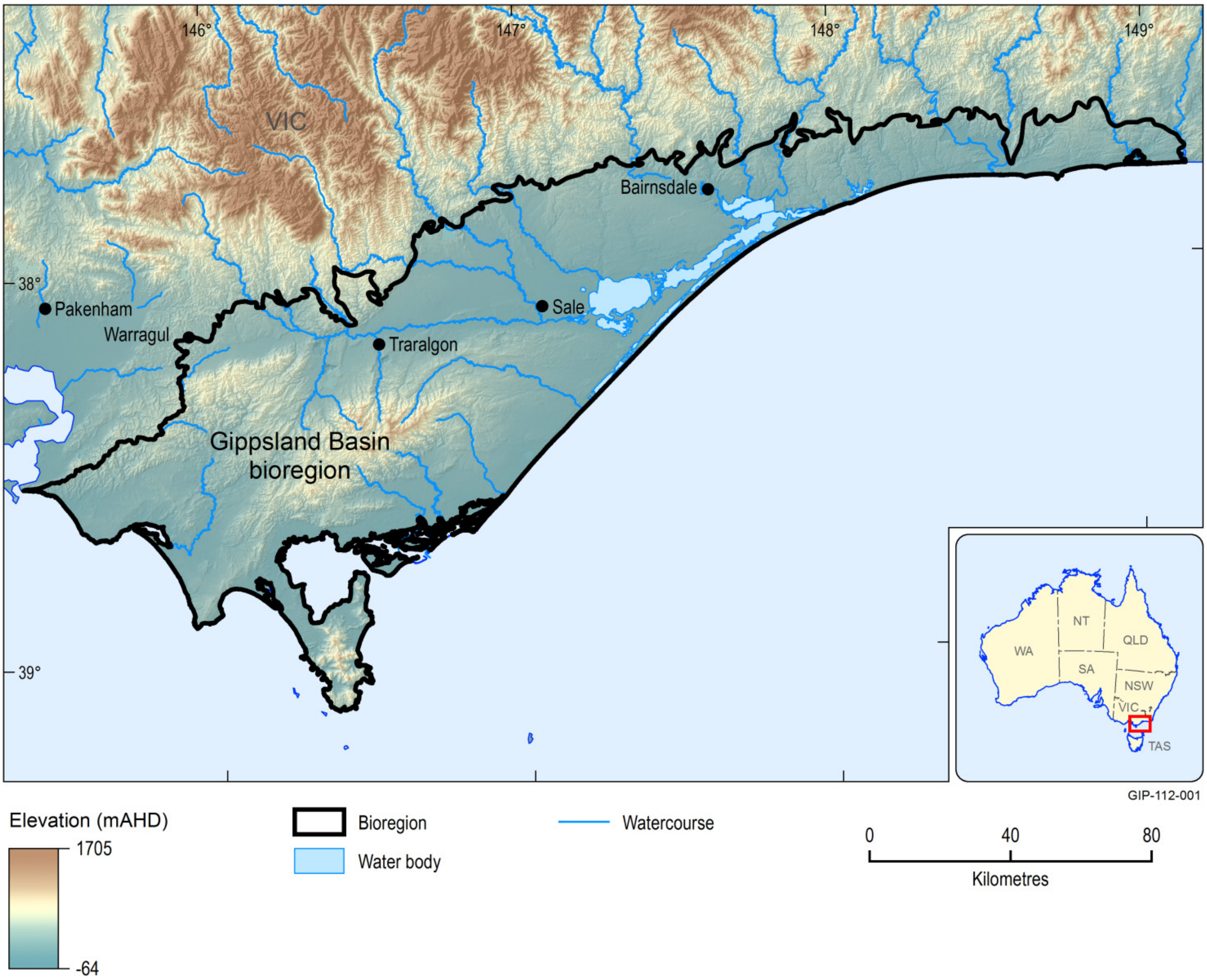


Figure 5 Surface elevation of the Gippsland Basin bioregion

Data: Geoscience Australia (Dataset 1)

1.1.2.1.2 Physiographic regions

Physiographic regions are areas with consistent landform and geological characteristics. The delineation of them can be useful for understanding wider characteristics of an area, as well as provide information regarding landscape features such as vegetation and soils (Pain et al., 2011). The physiographic regions of Australia have most recently been mapped in 2011 and use a hierarchical structure to define varying levels of physiographic divides. Divisions provide the largest delineation of areas of consistent landform, followed by Provinces and Regions at the smaller scale (Pain et al., 2011). Figure 6 shows the physiographic regions of the Gippsland Basin bioregion.

On a broad scale, the entirety of the Assessment area falls into the Eastern Uplands physiographic division, and the Kosciuszkan Uplands physiographic province, described as mountains and plateaux ranging from the highest point in Australia to the coast. Using the Region classification, the bioregion is primarily comprised of two physiographic regions, the South Victorian Uplands (covering 5751 km^2 or 39% of the region) and the Gippsland plains (covering 7780 km^2 or 53% of the region). The South Victorian Uplands cover the majority of the Strzelecki Ranges, the sloping plains south-west to the coast, and Wilsons Promontory. The Gippsland Plain physiographic region covers the remainder of the bioregion, from the Strzelecki Ranges east across the Gippsland plains to the border of the bioregion. In addition, the Assessment area also extends into the East Victorian Uplands physiographic region, although less than 8% of the bioregion falls in this region. The South Victorian Uplands physiographic region covers the Victorian Alps, the foothills of which are included in the Assessment area. These physiographic regions each exhibit different structural and regolith characteristics which are described in Table 3.

Table 3 Characteristics of the physiographic regions of the Gippsland Basin

Region	Region name	Region description	Regolith material
10710	South Victorian Uplands	Low fault blocks, mainly of tilted and dissected sandstone; granite hills and islands	Residual sand (20 to 50%), soil on bedrock (< 20%), residual clay (< 20%)
10711	Gippsland Plain	Terraced plains with sand and gravels	Highly weathered bedrock (> 50%), residual material (20 to 50%)
10707	East Victorian Uplands	Dissected high plateaux on various resistant rocks, with isolated high plains	Moderately weathered bedrock (> 50%), soil on bedrock (< 20%)

Data: CSIRO (Dataset 2)

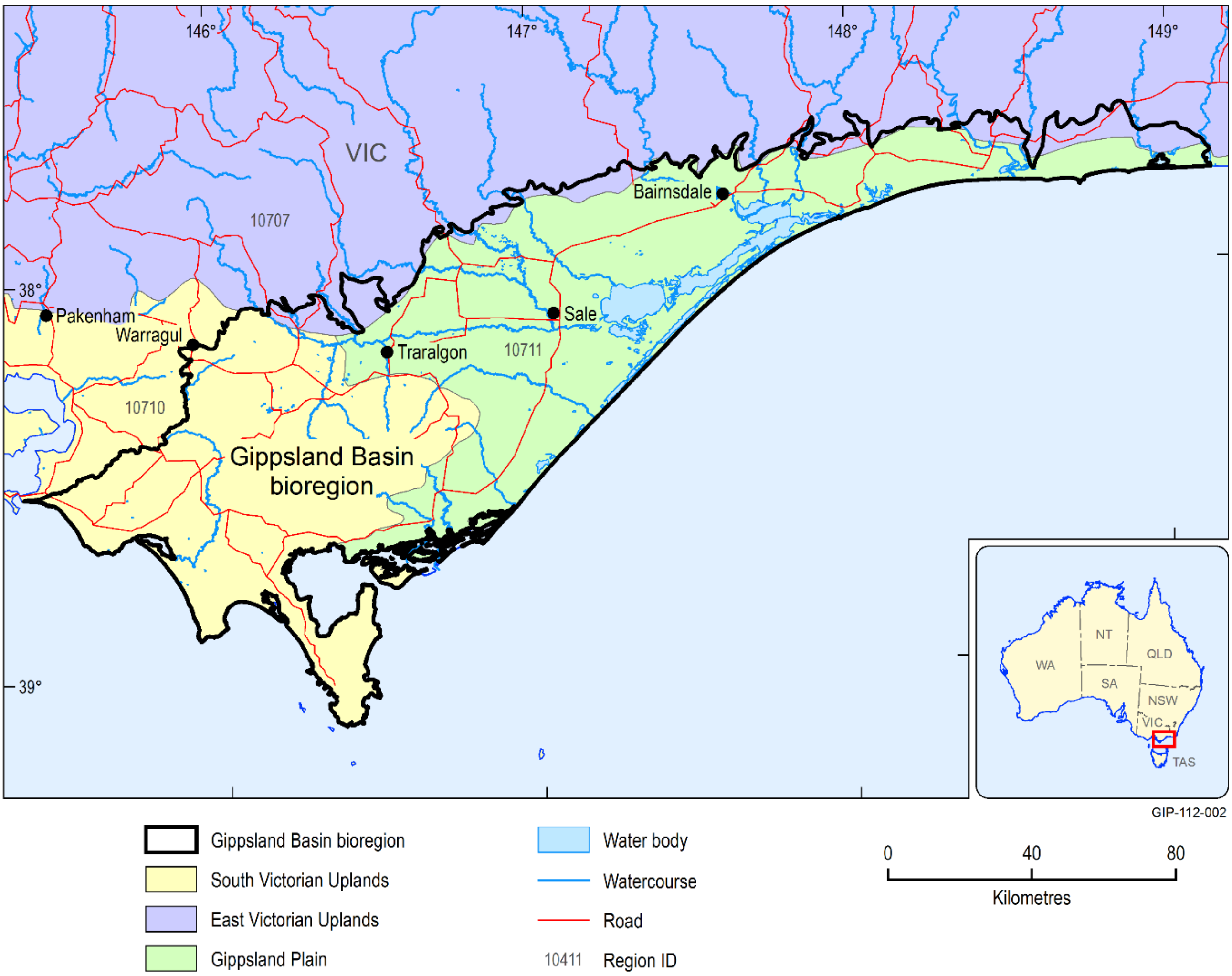


Figure 6 Physiographic regions of the Gippsland Basin bioregion

Data: CSIRO (Dataset 2)

1.1.2.1.3 Soils and land capability

The soil types of the Gippsland Basin bioregion generally align with the broad landscape features, and the underlying geology and physical location. The Australian Soil Classification developed by the CSIRO classifies soils into type based on the soil horizon characteristics and composition, and can be useful in understanding the potential capability of the soil (Isbell, 2002). Soil horizons are the layers parallel to the soil surface. Most soils generally have 3 to 4 horizons, with the characteristics of the soil often changing markedly between them. Generally horizon A (the surface soil below the organic matter), and horizon B (the subsoil, below the A horizon), are the most referred to in the classification. Horizon B is commonly further divided into sub-horizons. Weathered soils often have greater differences between the upper and lower horizons. Eleven soils types are represented across the Gippsland Basin bioregion, their distribution is shown in Figure 7. Table 5 shows the area and percentage of the bioregion covered by each soil type.

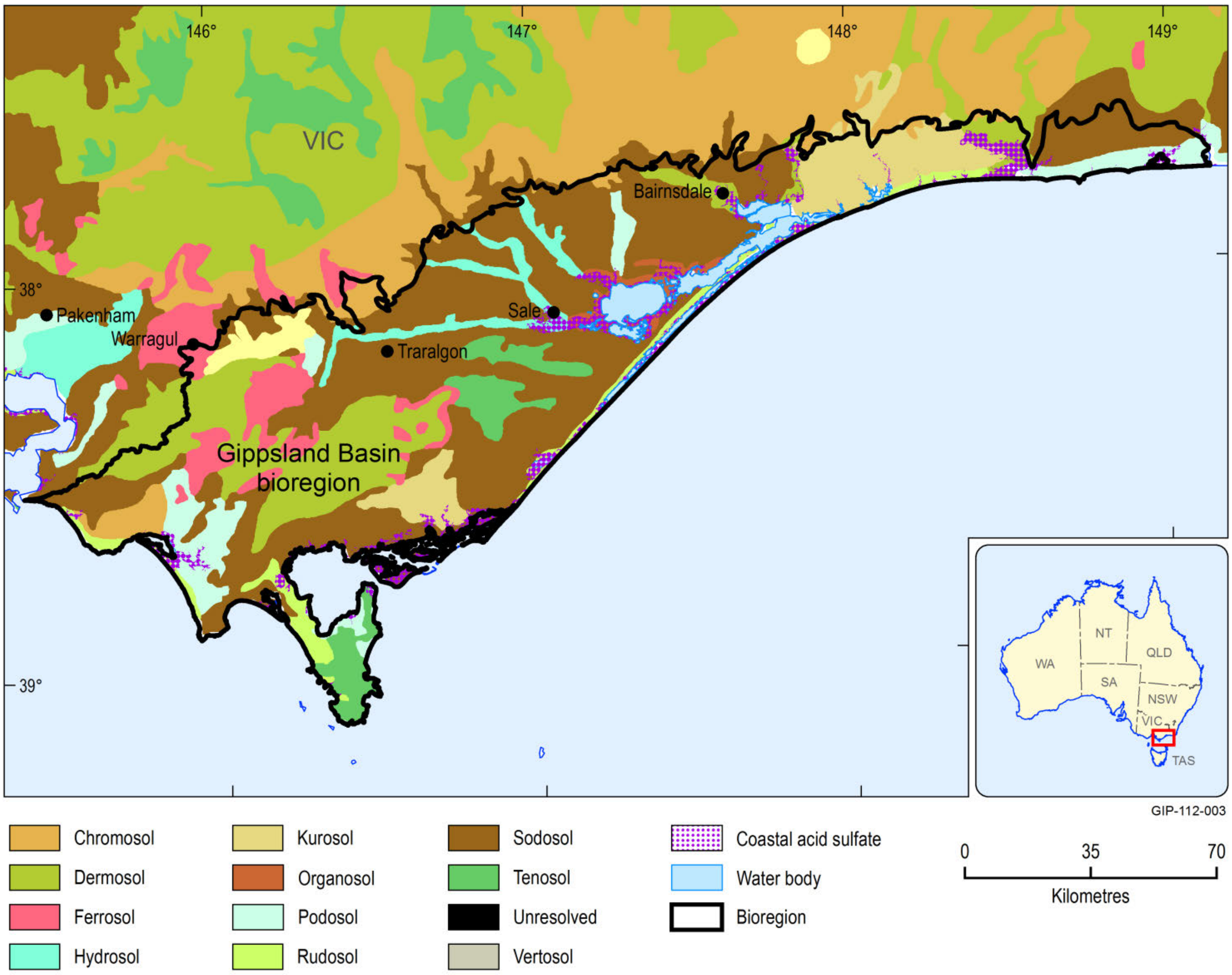


Figure 7 Classification of soils in the Gippsland Assessment area including location of potential coastal acid sulfate soils

Data: BRS (Dataset 3)

Table 4 Area and percentage of the Gippsland Basin bioregion by soil type

Soil class	Area (km^2)	Percentage of bioregion (%)
Sodosol	6539	46.3%
Dermosol	2030	14.4%
Kurosol	1154	8.2%
Podosol	868	6.1%
Tenosol	712	5.0%
Ferrosol	704	5.0%
Rudosol	589	4.2%
Hydrosol	444	3.1%
Chromosol	412	2.9%
Organosol	297	2.1%
Kandosol	226	1.6%

Data: BRS (Dataset 3)

The Gippsland plains, which receive less rainfall than other parts of the bioregion, are covered by Sodosols which have developed on a variety of Tertiary and Pleistocene sediments on the alluvial plains and terraces (Department of Environment and Primary Industries, 2014a). Sodosols are also present below the foothills of the Strzelecki Ranges to the south-west, and to the east of Marlo. They can be classified further into Red and Brown Sodosols, generally on the lower plains, and Yellow and Brown Sodosols on the shallow rises. Sodosols are classed with a strong difference in texture between the A (loamy) and B (clayey) horizons, and having sodic subsoils but not strongly acidic (Isbell, 2002). The high level of sodium results in the soils having a poor structure making them less permeable and susceptible to erosion (Gray, 2002). The Gippsland plains Sodosols are interspersed by Hydrosols (soils that are saturated at least 2 to 3 months per year) which follow the Latrobe, Thomson, Macalister and Avon river valleys and floodplains from the bioregion boundary to the Organosols surrounding Lake Wellington.

Bands of Rudosols have formed on sand dunes along 90 Mile Beach and along the coast east to Marlo. Rudosols have limited soil structure due to them being geologically new and there being insufficient time for a soil profile to develop. North of Marlo the coastal soils change to Podosols due to Aeolian deposition of siliceous sands during the Holocene epoch (Department of Environment and Primary Industries, 2014a). Similar areas of Podosols exists south-west of the Strzeleki Ranges around Inverloch and Venus Bay, and west of Morwell in the Latrobe Valley. Podosols are generally sandy soils with a relatively high amount of organic material in the

B horizon (Isbell, 2002). They are highly permeable, and due to this and their low fertility, have limited agricultural potential (Department of Environment and Primary Industries, 2014a).

Between Lakes Entrance and Marlo the soils are primarily Kurosols. Kurosols have strongly acidic subsoils with a pH less than or equal to 5.4 and a clear contrast between the A and B horizons (Department of Environment and Primary Industries, 2014a; Isbell, 2002). They generally have a low agricultural potential due to high acidity and permeability. In the south of the bioregion, surrounding Yarram there is another area dominated by Kurosols.

Along the eastern foothills of the Strzelecki Ranges the soils transition to Tenosols due to the drier steeper conditions. Tenosols are strongly acidic, often shallow soils with limited soil profile (Department of Environment and Primary Industries, 2014a; Isbell, 2002). Dermosols dominate the higher peaks of the Strzelecki Ranges, interspersed by Ferrosols. Dermosols generally have a similar texture between the A and upper subsoil B horizons (Isbell, 2002) and can be highly suitable for cropping as they are well structured and permeable (Department of Environment and Primary Industries, 2014a). The Ferrosols of the Gippsland region tend to be highly weathered, although they still have relatively high levels of organic matter and are reasonably fertile (Department of Environment and Primary Industries, 2014b). Ferrosols have similar texture between the A and B21 horizons, tend to form on tertiary basalts and have a high level of free iron, generally greater than 5% (Department of Environment and Primary Industries, 2014a; Isbell, 2002). They have good drainage but can dry out quickly due to low-water holding capacity. Ferrosols can be highly susceptible to erosion and compaction if cropping is not carefully managed (Department of Environment and Primary Industries, 2014b).

The Latrobe Valley soils are a mixture of Kandosols, Podosols and Sodosols. Kandosols are permeable, well-drained soils, with limited structure in the subsoils and a clay content of greater than 15%. They appear ‘earthy’ and have low fertility (Department of Environment and Primary Industries, 2014a). They occur on tertiary hills west of Morwell which is a geologically old landscape.

Wilsons Promontory is dominated by Tenosols, although Rudosols have developed in the rocky peninsula isthmus. Beyond the Assessment area to the north, as elevation increases towards the Victorian alpine region, the soils transition to Chromosols. Chromosols have a strong contrast between a loamy A horizon and an upper subsoil clayey B2 horizon which is not acidic and not sodic (Department of Environment and Primary Industries, 2014a).

Much of the soil in the Gippsland Basin bioregion is nutrient depleted due its age and natural weathering. Additionally, soil has been further depleted in some areas from extensive grazing and agriculture over a long period of time causing compaction and erosion of the fertile upper soil horizon. Despite this, the use of fertilisers and irrigation has enabled the region to become highly productive for crops, farming and forestry.

Acid sulfate soils have the potential to develop in some coastal areas of the Gippsland Basin bioregion. If these soils are disturbed, exposed or drained, sulfuric acid is produced through an oxidisation process. Acid sulfate soils have the potential to result in acidified soil and water leading to loss of vegetation, and decline in numbers of fish and other organisms. Contaminants (especially metals) can sometimes be released from acid sulfate soils as a result of oxidation which also has the potential to harm biota. Potential coastal acid sulfate soils have been mapped based on aerial photography, and field studies examining coastal geology, soil and water quality and topography (Department of Environment and Primary Industries, 2014c). These areas are highlighted in Figure 7.

1.1.2.1.4 Land cover

Figure 8 shows the land cover classification across the Gippsland Basin bioregion for the period of 2000 to 2008. The classification has been developed by Geoscience Australia and the Australian Bureau of Agriculture and Resource Economics and Sciences using snapshots of vegetation greenness from Enhanced Vegetation Index (EVI) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellites. Using the vegetation greenness from the EVI data, and its seasonal changes, a vegetation or land cover class has been assigned to each location (Lymburner, 2011).

The land cover of the Gippsland Basin bioregion is primarily classed as Trees (closed, open and sparse), Rain-fed Pasture and Irrigated Pasture. Table 5 presents the area and the percentage of the bioregion covered by each class. The Gippsland region is a high producer of dairy and this is reflected in the large percentage of the Assessment area being covered by pasture. The majority of pasture is found in the lower-lying Gippsland plains, and from the Strzelecki Ranges to the western bioregion boundary, including Leongatha and the coastal region. The Macalister Irrigation District, extending down the river valleys from Lake Macalister to Lake Wellington is classified, as expected, as Irrigated Pasture interspersed with Rainfed Pasture. Smaller areas of Irrigated Pasture exist along the Latrobe River, around Orbost, and in the west of the bioregion. The Strzelecki Ranges and Wilsons Promontory are primarily covered by trees, both closed and open, although the relative amounts of plantation and native forest is not consistent between the areas. The Latrobe Valley exhibits a mix of land cover including trees, pasture and sedges. East of Lakes Entrance the land cover is predominately closed trees. The inland water bodies cover 3.5% of the bioregion.

Much of the bioregion has been cleared of native vegetation. The *2001 Nature Conservation Review of Victoria* estimated that of pre-1750 vegetation only 21% of the Gippsland plains and 19% of the Strzelecki Ranges remains mainly unaltered by human activity (Porter, 2001). The vegetation of Wilsons Promontory is the only large expanse of the bioregion that has remained unaltered since pre-1750 (Porter, 2001). Much of the removal and modification of native vegetation has been for pasture and forestry.

Table 5 Area and percentage of the Gippsland Basin bioregion by land cover class

Land cover class	Area (km^2)	Percentage of bioregion (%)
Trees (closed, open, scattered, sparse)	7856	46%
Rainfed pasture	7638	44.9%
Irrigated pasture	770	4.5%
Inland waterbodies	598	3.5%
Grasses	58	0.3%
Shrubs (open, scattered and sparse)	45	0.3%
Sedges – open	25	0.15%
Rainfed cropping	9	0.1%
Salt lakes	6	<.1%
Extraction sites	<1	<0.1%
Forbs (open and sparse)	<1	<0.1%

Data: Bioregional Assessment Programme (Dataset 4)

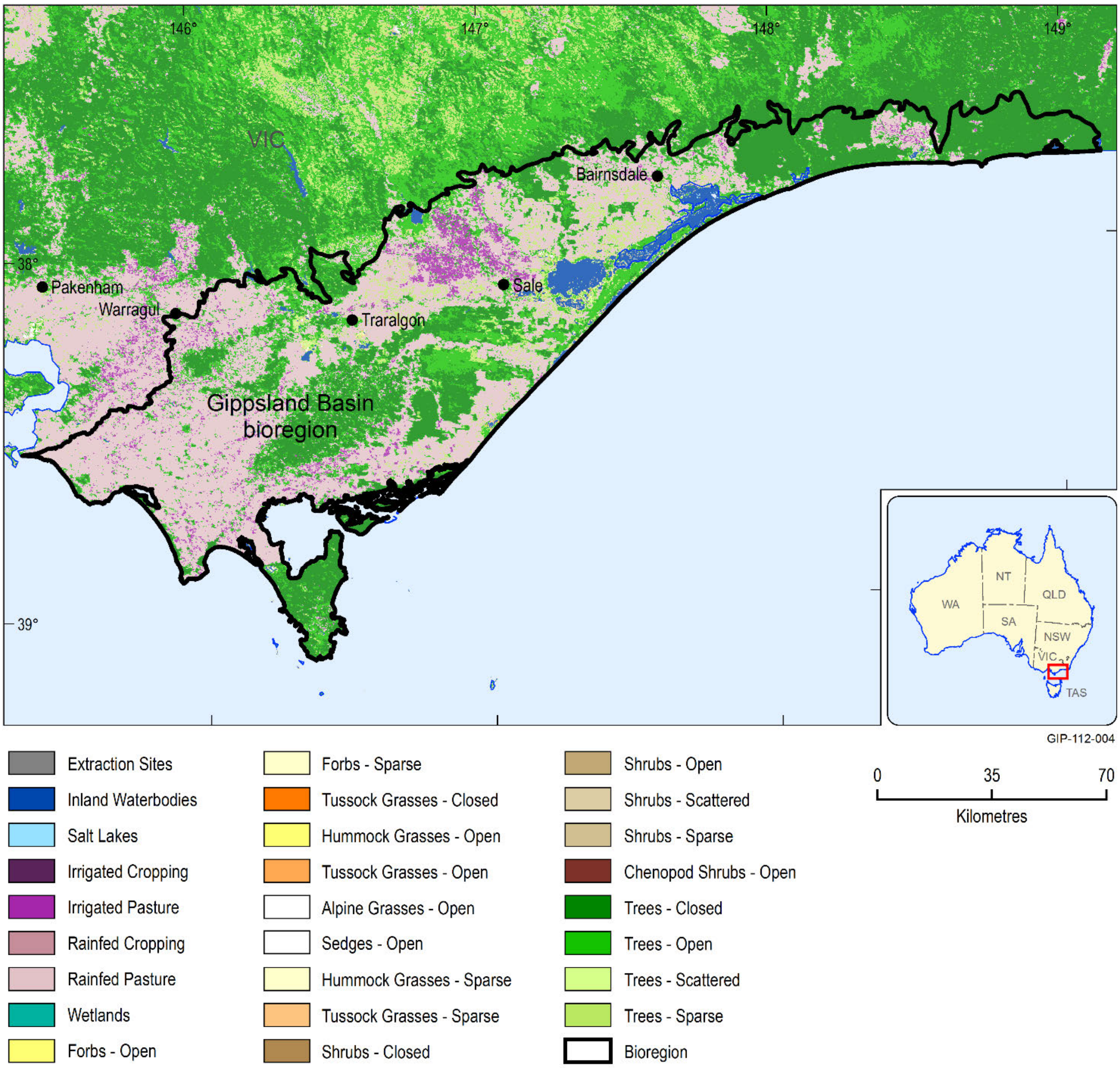


Figure 8 Land cover of the Gippsland Basin bioregion

Data: Bioregional Assessment Programme (Dataset 4)

1.1.2.2 Human geography

1.1.2.2.1 Population

The overall population of the Gippsland Basin bioregion has been estimated at 203,445 based on the population counts of the 2011 Australian Bureau of Statistics (ABS) census mesh blocks which fall within the Assessment area (Australian Bureau of Statistics, 2011a; 2011b). Using the same method, the number of houses in the bioregion is estimated at 101,903. There are six Victorian local government areas (LGAs) present in the Gippsland Basin bioregion, although none are fully included in the area of the bioregion. Approximately 90% of Latrobe, 90% of South Gippsland, 50% of Bass Coast, 50% of Wellington, 30% of Baw Baw, and 20% of East Gippsland LGAs intersect the Gippsland Basin bioregion (Australian Bureau of Statistics, 2011b). The ABS statistical areas level 3 (SA3) broadly align with the Victorian LGAs, although Bass Coast and South Gippsland LGAs are combined in the SA3. Figure 9 shows the LGA boundaries as well as the population density of the Gippsland Basin bioregion based on the 2011 census mesh block counts.

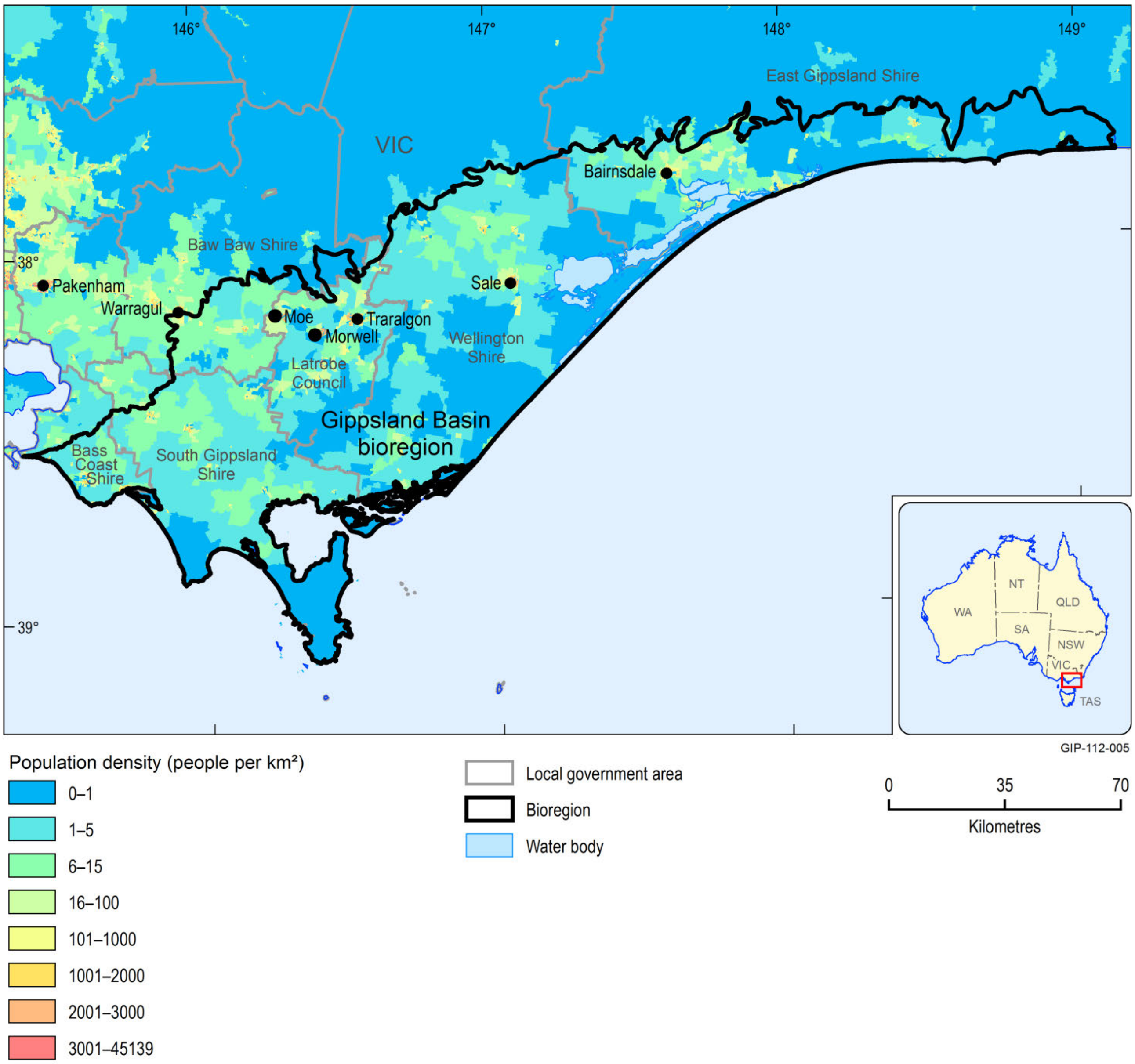


Figure 9 Population density of the Gippsland Basin bioregion

Data: ABS (Dataset 5)

The population is dispersed throughout the region, with over 40% of the population residing in towns with less than 1000 people (Gippsland Regional Plan Project Control Group, 2010). Although there are no major cities falling within the Assessment area, there are six population centres in the bioregion which had a population of over 10,000 in 2011. These include Traralgon (24,590), Moe (13,691), Morwell (13,691), Warragul (13,081), Sale (12,766), and Bairnsdale (11,820) (Australian Bureau of Statistics, 2001 & 2011). Most of these larger towns are situated along the main access road, the Princes Highway. Across the bioregion there are an additional 48 small towns ranging in population from around 200 to 7279 including: Lakes Entrance, Wonthaggi, Leongatha and Maffra. Table 6 presents the 2001 and 2011 census population of the main town centres of the Gippsland Basin bioregion, and the population change between years.

Table 6 Main population centres of the Gippsland Basin bioregion and their population change from 2001 to 2011

Urban centre or locality (ABS[a])	2001 Population	2011 Population	2001 to 2011 Population change (number)	2001 to 2011 Population change (%)
Traralgon	19,569	24,590	5,021	25.7%
Moe	15,352	15,292	–60	-0.4%
Morwell	13,505	13,691	186	1.4%
Warragul	10,405	13,081	2,676	25.7%
Sale	12,793	12,766	–27	–0.2%
Bairnsdale	10,557	11,820	1,263	12.0%
Wonthaggi	6,136	7,279	1,143	18.6%
Lakes Entrance	5,476	5,965	489	8.9%
Leongatha	4,220	4,894	674	16.0%
Maffra	3,900	4,262	362	9.3%
Paynesville	2,848	3,236	388	13.6%
Orbost	2,085	2,143	58	2.8%
Total	106,846	119,019	12,173	11.4%

Data: ABS (2001, 2011)
[a]Australian Bureau of Statistics

Unlike other rural areas of Australia, the rural population of Gippsland is not in decline (Gippsland Regional Plan Project Control Group, 2010). Since 1996 the population has increased by approximately 30,000 residents (Joint Commonwealth and Victorian Regional Forest Agreement Streering Committee, 1999). Currently the Baw Baw and Bass Coast LGAs are among the fastest growing in Victoria (Gippsland Regional Plan Project Control Group, 2010) and substantial population increases are predicted for the South Gippsland LGA population (Strategic Planning and Development Department, 2014). The overall population of the Gippsland region is predicted to increase by approximately 50,000 (20%) by 2026, with a large increase in the number of people over 65 years of age (Gippsland Regional Plan Project Control Group, 2010). This value has been calculated for a wider extent than the bioregion, but it does suggest that the bioregion is likely to experience significant population growth. Table 7 shows the population growth between 2011 and 2012 for the local government areas represented in the bioregion. Overall the population growth is greater in the western parts of the bioregion compared to the east. This is due to the expansion of the outer suburbs of Melbourne.

Table 7 Population growth by local government area between 2011 and 2012 for the Gippsland Basin bioregion

ABS[a] statistical area (SA3[b])	Local government area	Estimated resident population June 2011	Estimated resident population June 2012	2011 to 2012 population change (number)	2011 to 2012 population change (%)
Baw Baw	Baw Baw (S)	43,416	44,375	959	2.2%
Gippsland – South West	Bass Coast (S)	30,024	30,367	343	1.1%
	South Gippsland (S)	27,506	27,802	296	1.1%
Gippsland East	East Gippsland (S)	42,793	43,103	310	0.7%
Wellington	Wellington (S)	41,945	42,147	202	0.5%
Latrobe Valley	Latrobe (C)	73,564	73,672	108	0.1%

Data: ABS (Dataset 6)
[a]Australian Bureau of Statistics, [b]statistical areas level 3

1.1.2.2.2 Economic activity

The economy of Gippsland is primarily based on agriculture, forestry, dairy and mining with a gross regional product estimated at $13.26 billion. This equates to approximately 5% of Victorian Gross Domestic Product (GDP) (Gippsland Regional Plan Project Control Group, 2010). Despite over 30% of businesses in the area being related to the agriculture and fishing industries, the key economic industries are electricity generation, oil and gas production, manufacturing and water supply (Gippsland Regional Plan Project Control Group, 2010).

Approximately 90% of Victorian power is generated from three power stations within the bioregion at Yallourn, Hazelwood and Loy Yang, with coal sourced from the Latrobe Valley. Mining of brown coal began in the Gippsland Basin bioregion in 1826 (Morgan, 1997), with extensive mining of the Latrobe Valley coal resources beginning in the 1920s (Joint Commonwealth and Victorian Regional Forest Agreement Streering Committee, 1999). It is estimated that 430 Bt of brown coal remain in situ in the Latrobe Valley, with 33 Bt of economic resource (Gippsland Regional Plan Project Control Group, 2010). In addition, conventional oil and gas from the Gippsland Basin contributes approximately 20% of Australias production (Gippsland Regional Plan Project Control Group, 2010).

The Gippsland region contributes over 20% of national milk production (GippsDairy, 2013). Dairy farming and manufacturing of dairy products is the largest employer in the South Gippsland region. The Macalister Irrigation District is a key dairy, agriculture and forestry area and covers approximately 530 km^2 between Sale and Lake Glenmaggie following the Macalister and Thomson river valleys (Southern Rural Water, 2014).

Forestry has been a key economic element of the region since the 1840’s. The Strzelecki Ranges were initially cleared of native vegetation by 1900 and have since been used for forestry (Joint Commonwealth and Victorian Regional Forest Agreement Streering Committee, 1999).

South Gippsland attracts approximately a million visitors annually, with a focus on natural environments such as Wilsons Promontory and the Gippsland Lakes (Strategic Planning and Development Department, 2014). The total annual output from tourism in the region was estimated at $837.4 million in 2010 (Gippsland Regional Plan Project Control Group, 2010). A key strategy of the Gippsland Regional Plan is to better manage the Gippsland Lakes tourism region to better cope with high tourist number and growing population (Gippsland Regional Plan Project Control Group, 2010).

From 2006 to 2010 the number of jobs rose by around 6000 (Gippsland Regional Plan Project Control Group, 2010). Due to the relatively high numbers of retirees, the region has one of the lowest employment participation rates in Victoria (Gippsland Regional Plan Project Control Group, 2010).

1.1.2.2.3 Land use

The land use of the Gippsland Basin bioregion closely relates to the economic activities in the region (Table 8, Figure 10), with the majority of land used for production from dryland agriculture and plantations (Australian Bureau of Agricultural and Resource Economics and Sciences, 2014). Conservation and natural environments is the second largest land use with 17% of the bioregion, much of it public land, used for conservation and preservation of the natural environment. Many of these areas are important for tourism including the Gippsland Lakes and Corner Inlet, Wilsons Promontory, Walhalla (Australian Alps Walking Track) and the Strzelecki Ranges.

Table 8 Area and percentage of the Gippsland Basin bioregion covered by land use category

Primary land use category	Area (km^2)	Percentage of bioregion (%)
Production from dryland agriculture and plantations	8217	56.3%
Conservation and natural environments	2479	17.0%
Intensive uses	1604	11.0%
Production from relatively natural environments	1403	9.6%
Production from irrigated agriculture and plantations	540	3.7%
Water	365	2.5%

Data: Geoscience Australia (Dataset 7)

Land use in the Strzelecki Ranges is primarily for softwood forestry. The Ranges were initially cleared of native vegetation by 1900 and have since been used for forestry (Joint Commonwealth and Victorian Regional Forest Agreement Streering Committee, 1999). Although some areas are protected in nature reserves (Tarra-Bulga National Park, Morwell National Park, Mount Worth State Park). Two Regional Forest Agreements (RFA) cover large segments of the Assessment area - the Gippsland RFA and the East Gippsland RFA – and govern the land use and forestry practices allowable.

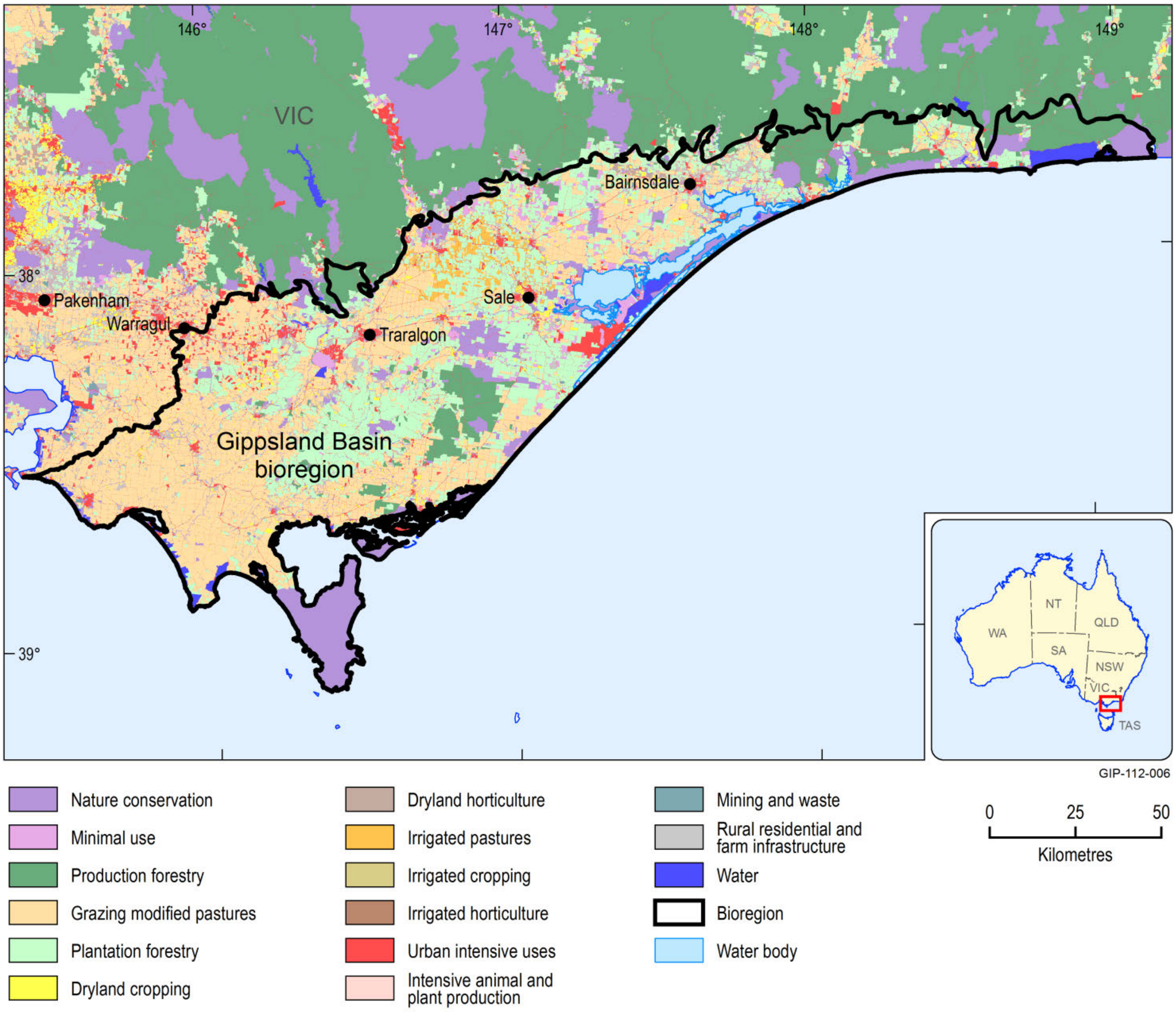


Figure 10 Land use of the Gippsland Basin bioregion

Data: Geoscience Australia (Dataset 8)

1.1.2.2.4 Water storage

There is 60% of Melbourne's water sourced from catchments in the Gippsland region (Gippsland Regional Plan Project Control Group, 2010). In addition the majority of the industries present in the bioregion are reliant on water supply. Southern Rural Water is responsible for water supply management across the region, and maintain four major water storage locations in the Gippsland Basin bioregion: Lake Glenmaggie, Cowwarr Weir, Blue Rock Dam and Lake Narracan (Southern Rural Water, 2014). Gippsland Water maintains the Moondarra Reservoir, and Melbourne Water maintains numerous water storages north of the bioregion including the Thomson Reservoir which is the largest water storage in Melbourne's water supply, providing the majority of Melbourne's water (Melbourne Water, 2014). Table 9 lists the storage capacity, catchment area and discharge capacity of each. The locations of the major storages are shown in Figure 12.

Table 9 Water storages of the Gippsland Basin bioregion

Water storage	Storage capacity (ML)	Catchment area (km^2)	Discharge capacity (ML/day)
Lake Glenmaggie	177,640	1891	300,000
Cowwarr Weir	210	1100	80,000
Blue Rock Dam	208,190	360	100,000
Lake Narracan	7,230	1942	268,000
Thomson Reservoir	1,068,000	487	Unknown

Data: Melbourne Water (2014), Southern Rural Water (2014)

Lake Glenmaggie provides water to the Macalister Irrigation District through three main irrigation channels: Main Northern (capacity 500 ML/day), the Main Southern (capacity 1460 ML/day) and the Main Eastern (capacity 600 ML/day) (Southern Rural Water, 2014). The Macalister Irrigation District 2030 Plan describes the management of the 600 km of irrigation channels (Gippsland Regional Plan Project Control Group, 2010).

In 2012 the Victorian Desalination Plant was developed near Wonthaggi in order to supplement the standard catchment water supply during periods of low rainfall. The plant has a production capacity of 150 GL/year (Aquasure, 2014). In addition, the Gippsland Water Factory at Maryvale processes wastewater from over 19,000 properties and the Maryvale Paper Mill producing water for industrial use (Gippsland Regional Plan Project Control Group, 2010).

1.1.2.2.5 Indigenous heritage

The Kurnai Indigenous nation (now known as Gunnai) covered what is now the Gippsland region before European settlement. By 1850 the native population had been severely reduced due to disease, massacres and declining birth rates (Morgan, 1997).

Indigenous land use agreements are present over much of the region. The Gunaikurnai Settlement Indigenous Land Use Agreement (ILUA) covers approximately 13,390 km^2 within the Gippsland Basin bioregion, between the coast and the Great Dividing Range from Moe to the Snowy River. The agreement has been in effect since 2010 and was the first to be formalised under the new Victorian native title settlement framework (Bourova, 2011).

1.1.2.3 Climate

The climate across the Gippsland Basin bioregion is influenced by the geography, topography, elevation and distance from the coast. The climate is considered temperate under the Koppen-Geiger climate classification scheme (Koppen-Geiger classification, dataset 9). Within the bioregion the climate is monitored from 263 weather stations (Bureau of Meteorology, 2014).

1.1.2.3.1 Rainfall and aridity

The mean long-term annual precipitation across the bioregion is 835 mm (Figure 11). The Great Dividing Range to the north has a significant influence on the rainfall and weather patterns of the bioregion, and contributes to the rain-shadow in the Mitchell and Tambo river valleys, and the Gippsland plains from Sale to Bairnsdale (Joint Commonwealth and Victorian Regional Forest Agreement Steering Committee, 1999). As a result, these areas receive on average 500 to 700 mm rainfall annually.

Figure 12 shows the mean annual rainfall for the entire bioregion. Although there is no dry season, the maximum rainfall on average occurs during winter and spring, with the least seasonal variation apparent in the low-lying plains (Joint Commonwealth and Victorian Regional Forest Agreement Streering Committee, 1999).

The Gippsland plains and lower-lying areas are prone to flooding during high rainfall events. Flood events in 1998 and 1971, and severe storms in 2007 are estimated to have cost the region $3, $53 and $18 million respectively (Insurance Council of Australia, 2014). Increases in population in the coming decades are predicted to lead to increases in the costs when disasters do occur in the region (Foster H, 2013).

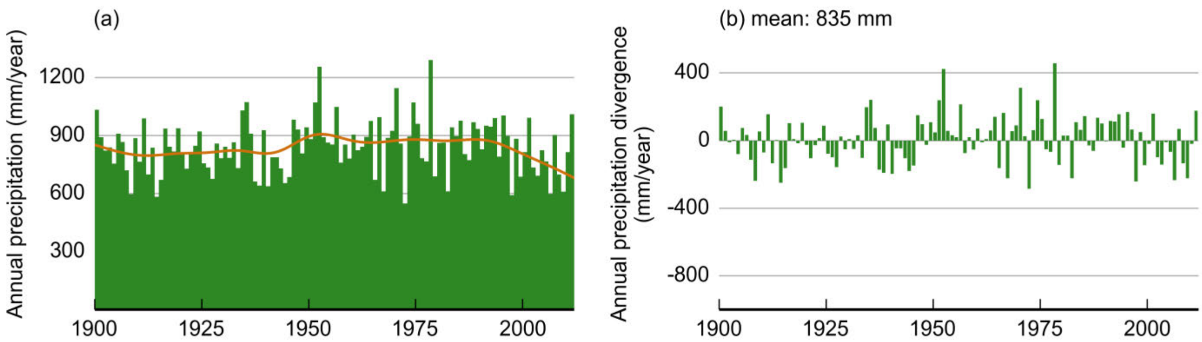


Figure 11 (a) Annual rainfall with smoothed rolling average and (b) annual rainfall divergence from the long-term mean for the Gippsland Basin bioregion

Data: CSIRO Land and Water (Dataset 10)

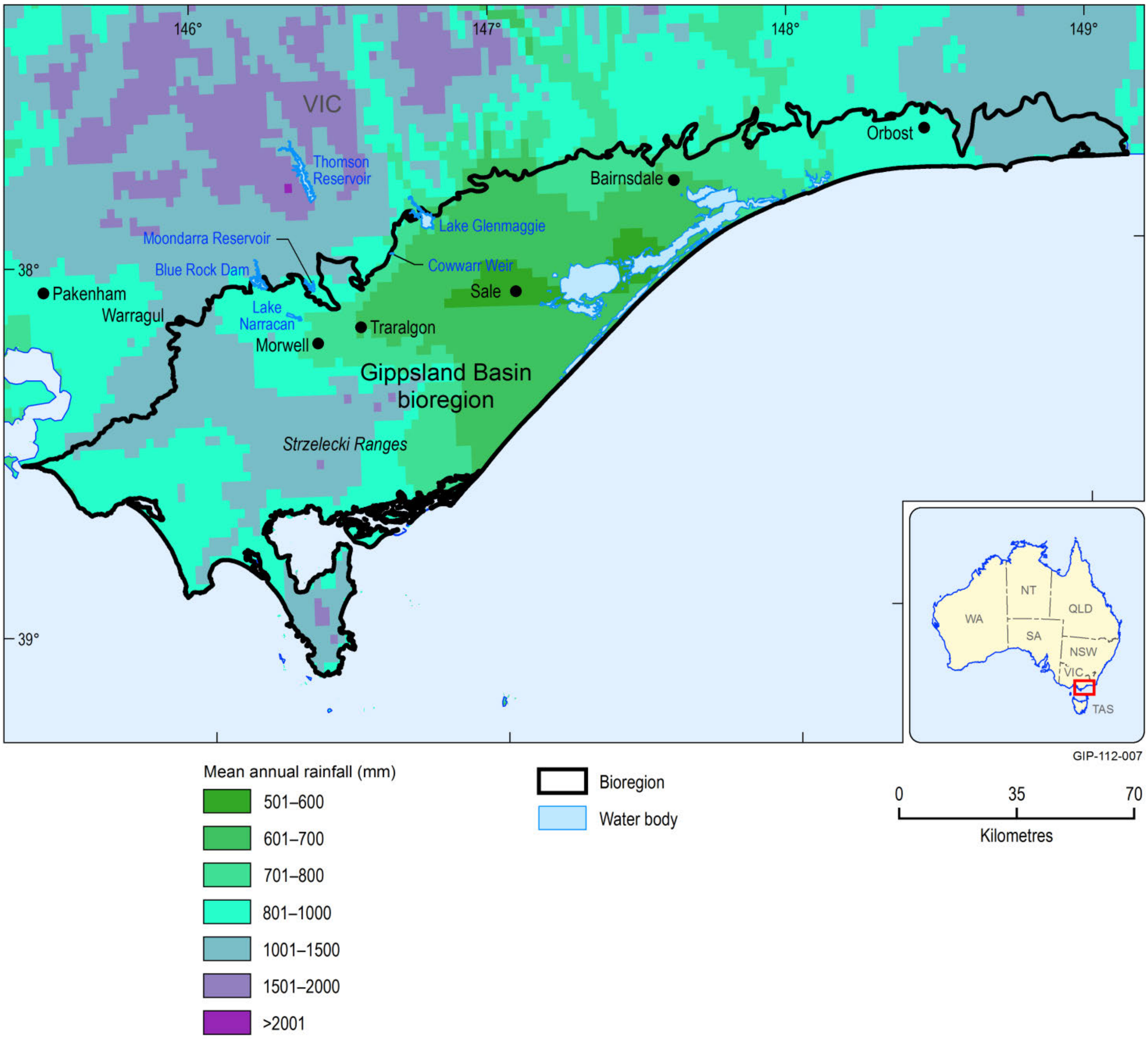


Figure 12 Mean annual rainfall across the Gippsland Basin bioregion

Data: Bureau of Meteorology (Dataset 11)

Rainfall levels combined with the potential evapotranspiration (PET) largely determine the relative moisture availability of an area. Across the Gippsland Basin bioregion PET is generally higher on the elevated peaks, and the eastern part of the bioregion. When combined with rainfall into an aridity index (Figure 13) it can be seen that the driest areas are the Gippsland plains from Morwell to Bairnsdale, with relatively greater moisture available on, and to the west of the Strzelecki Ranges, as well as the eastern region surrounding Orbost. Over the year, PET is highest during summer, reaching over 200 mm/month, and lowest during winter, dropping to less than 50 mm/month (Figure 11). Due to relatively stable precipitation, the annual aridity follows a similar trend.

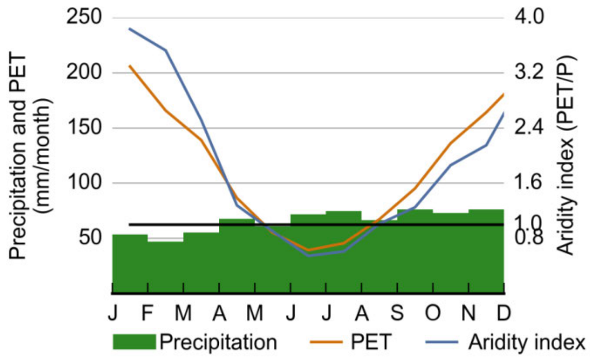


Figure 13 Mean monthly precipitation, potential evapotranspiration (PET) and aridtiy index for the Gippsland Basin bioregion. The black line indicates an aridity index of 1, where precipitation and PET are equal.

Data: CSIRO Land and Water (Dataset 10)

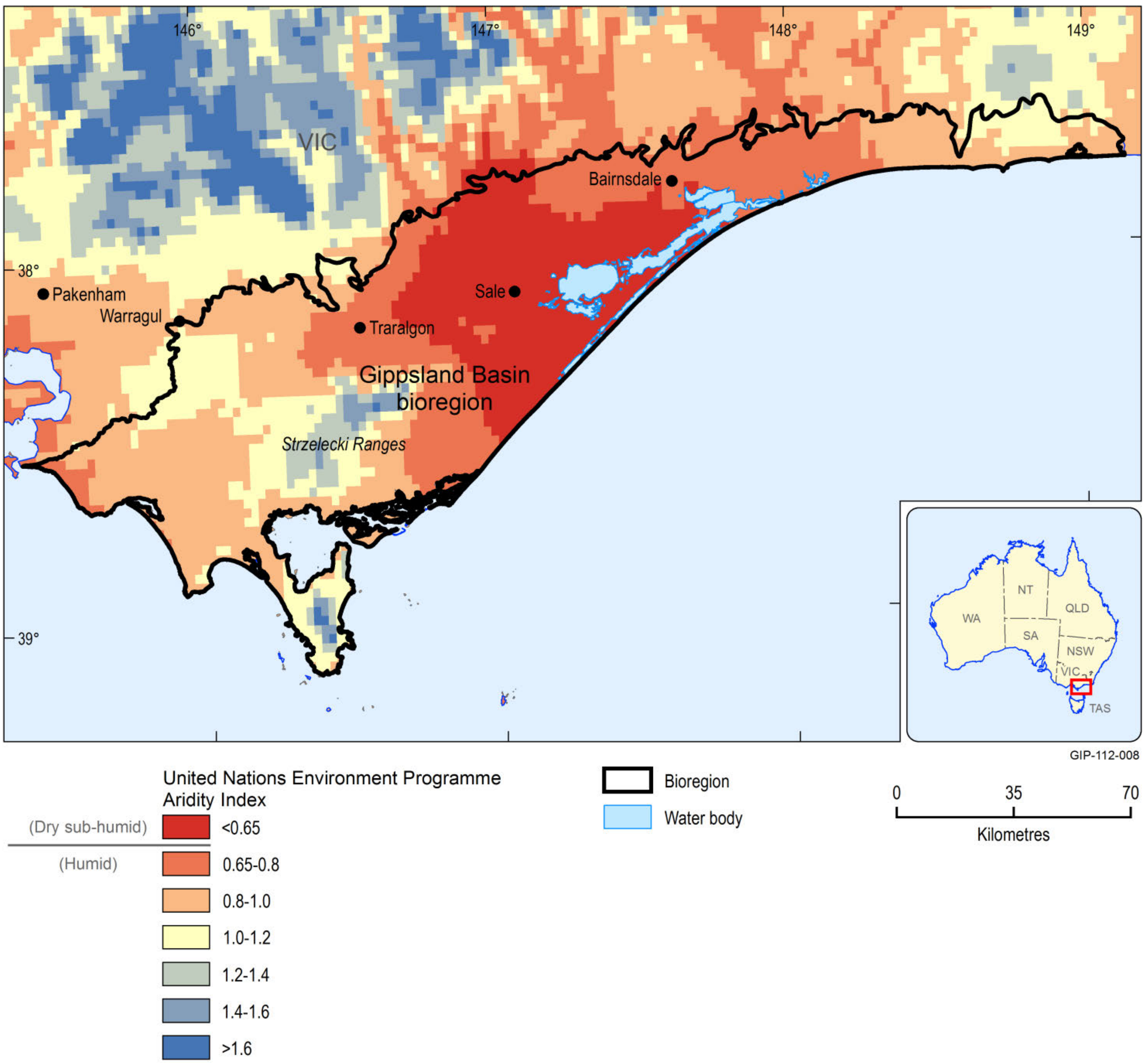


Figure 14 Aridity Index values across the Gippsland Basin bioregion

Data: Bureau of Meteorology (Dataset 12)

1.1.2.3.2 Temperature

Altitude and proximity to the coast are the main drivers of temperature across the bioregion. The region experiences summers with mean maximum temperatures around 24 °C and mean minimums of around 13 °C. Winter temperatures range from 5 to 14 °C. The hottest temperatures are generally experienced in the area surrounding Sale, and the coolest in the Strzelecki Ranges. The Gippsland plains are comparatively hotter due to descending winds from the Victorian Alps (Joint Commonwealth and Victorian Regional Forest Agreement Streering Committee, 1999). Figure 15 shows the range of minimum and maximum temperatures by month.

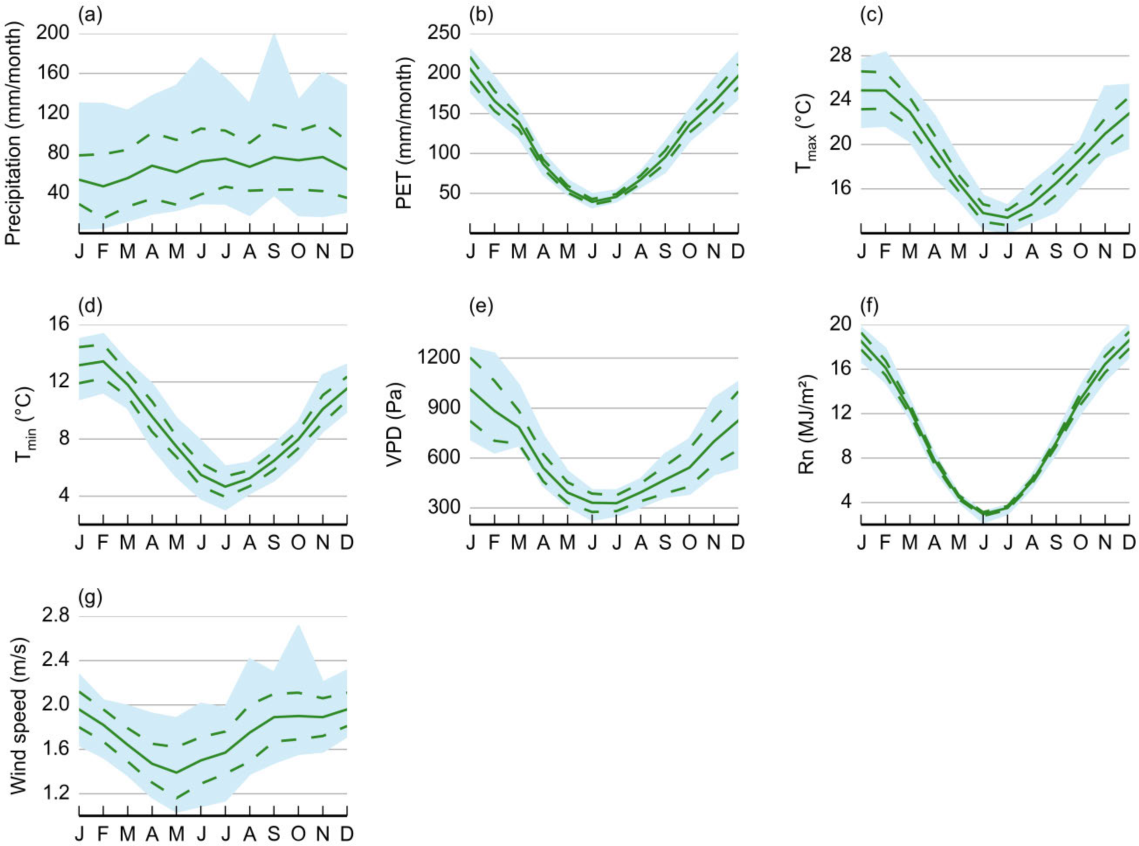


Figure 15 Monthly mean values of (a) precipitation,(b) potential evapotranspiration (PET), (c) maximum temperature (Tmax), (d) minimum temperature (Tmin), (e) vapour pressure deficit (VPD), (f) net radiation (Rn) and (g) wind speed for the Gippsland Basin bioregion

Data: CSIRO Land and Water (Dataset 10)

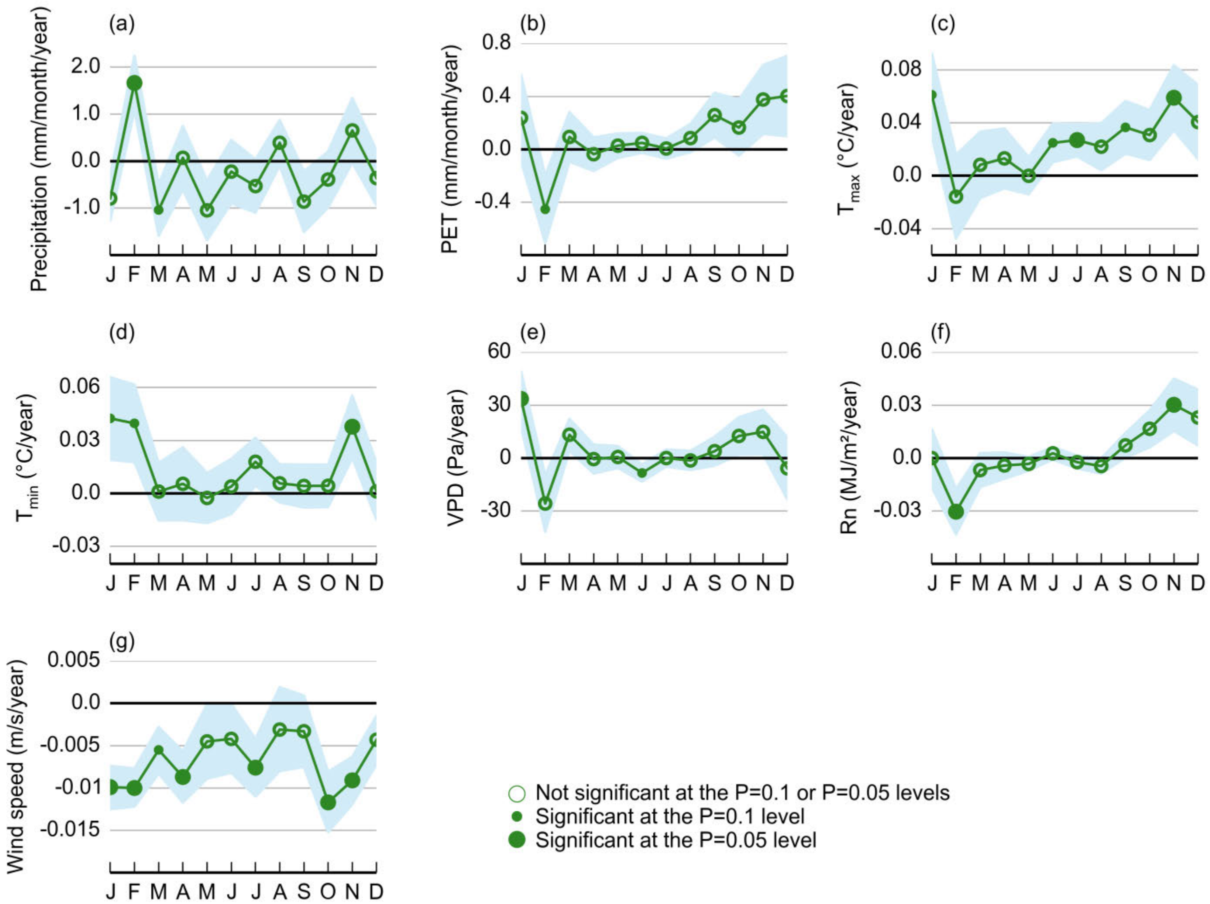


Figure 16 Annual trend by month of (a) precipitation, (b) potential evapotranspiration (PET), (c) maximum temperature (Tmax), (d) minimum temperature (Tmin), (e) vapour pressure deficit (VPD), (f) net radiation (Rn) and (g) wind speed for the Gippsland Basin bioregion, where P represents the statistical significance level.

Data: CSIRO Land and Water (Dataset 10)

1.1.2.3.3 Future climate projections

Table 10 and Table 11 present the projected climate outcomes for the catchments in the region for 1 and 2 degrees of warming, combined with either a dry extreme, median or wet extreme scenario (Post DA, 2012). These outcomes were determined through the South Eastern Australian Climate Initiative (SEACI) study which performed modelling analysis on 15 global climate models (GCMs) and daily rainfall and areal potential evapotranspiration statistics from 1895 to 2008. In all warming scenarios it is predicted that the annual rainfall and runoff will reduce compared to the historical mean. The exceptions are the Snowy River and Tambo River catchments which under the wet extreme scenario either have a small increase in rainfall and runoff, or stay consistent with current levels. As expected, the climate scenario of 2 degrees of warming produces a greater reduction, with worst-case predictions of up to a 17% reduction in rainfall and 41% reduction in runoff occurring for the Tambo river basin under a dry extreme scenario. Although there is inherent uncertainty in the projected outcomes, for all catchments the majority of GCMs project a decrease in future rainfall and runoff under both a 1 and 2 degrees of warming.

The reliance of the Gippsland Region economy on natural resources makes the area potentially more susceptible to negative consequences from climate change. In particular a reduction in rainfall is cited as the greatest climate threat to the region (Gippsland Regional Plan Project Control Group, 2010).

Table 10 Predicted degree of change to rainfall for the catchments in the Gippsland Basin bioregion under two global warming scenarios

Basin	Historical rainfall (mm)	1 °C of global warming			2 °C of global warming		
		Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
Latrobe	982	–7%	–5%	–2%	–15%	–9%	–3%
Mitchell River	969	–8%	–4%	–1%	–16%	–9%	–3%
Snowy River	774	–7%	–3%	3%	–14%	–6%	6%
South Gippsland	892	–7%	–4%	–2%	–14%	–9%	–3%
Tambo River	790	–9%	–4%	0%	–17%	–8%	1%
Thomson River	926	–8%	–5%	–2%	–16%	–9%	–3%

Data: Post et al. (2012)

Table 11 Predicted degree of change to runoff for the catchments in the Gippsland Basin bioregion under two global warming scenarios

Basin	Historical runoff (mm)	1 °C of global warming			2 °C of global warming		
		Dry extreme	Median	Wet extreme	Dry extreme	Median	Wet extreme
Latrobe	181	–21%	–14%	–6%	–37%	–25%	–9%
Mitchell River	219	–20%	–12%	–4%	–35%	–22%	–6%
Snowy River	106	–19%	–8%	7%	–34%	–15%	15%
South Gippsland	155	–20%	–13%	–6%	–36%	–24%	–10%
Tambo River	74	–24%	–12%	2%	–41%	–21%	5%
Thomson River	203	–19%	–12%	–3%	–35%	–22%	–5%

Data: Post et al. (2012)

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1.1.3 Geology

Summary

The geological Gippsland Basin covers an area around 46,000 km^2. The basin widens and deepens to the east and about 70% of the basin occurs offshore beneath the present-day continental shelf. It is bounded to the north by Paleozoic basement rocks of the Eastern Highlands, to the west by uplifted Lower Cretaceous Strzelecki Group fault blocks of the Strzelecki Ranges, and by the Bassian Rise in the south-west which separates it from the Bass Basin. The Gippsland Basin began to form in the Early Cretaceous in response to rifting between Australia and Antarctica around 150 Ma.

Within the Gippsland Basin there are three major stratigraphic groups: the Early Cretaceous Strzelecki Group, the Late Cretaceous to Eocene Latrobe Group and the Oligocene to Pliocene Seaspray Group. Deposition of each of these groups was preceded by a major tectonic event resulting in erosional unconformities that define the base of each group and are presumed to be continuous across the basin.

The Gippsland Basin is Australia's premier hydrocarbon basin, hosting very large oil and gas reserves that supply gas markets in Victoria, NSW and Tasmania. These reserves are found in the Latrobe Group sediments. The Gippsland Basin also hosts some of the largest brown coal deposits in the world within the Eocene to Miocene age Latrobe Valley Group coal measures. These coal measures are mined for electricity generation for the Victorian market. The Gippsland Basin may also be prospective for coal seam gas and tight gas hosted within the Latrobe Group and Strzelecki Group respectively.

This geological overview of the Gippsland Basin bioregion has synthesised the existing geoscientific knowledge of the Gippsland Basin, Moe Swamp sub-basin and Tarwin sub-basin, concentrating on the onshore part of the basin. The offshore part of the basin is not in-scope for the bioregional assessment. However, the offshore Gippsland Basin is covered in the detail required to inform discussion of coal resource development in the onshore part of the basin.

1.1.3.1 Geological structural framework

1.1.3.1.1 Definition of the basin, basin extent and regional geological context

The Gippsland Basin covers an area around 46,000 km^2. The basin widens and deepens to the east and about 70% of the basin occurs offshore beneath the present-day continental shelf (Holdgate and Gallagher, 2003). The basin is approximately 400 km long and 80 km wide, extending onshore from the Mornington Peninsula in the west to the edge of the continental shelf in the east. The boundaries of the basin are roughly defined by the Lake Wellington Fault System to the north, the Foster Fault system to the south, the Selwyn Fault to the west (near Western Port) and the Gippsland Rise to the east (Duddy, 2003) (see Figure 17). It is bounded to the north by Paleozoic basement rocks of the Eastern Highlands, to the west by uplifted Lower Cretaceous Strzelecki Group fault blocks and by the Bassian Rise in the south-west which separates it from the Bass

Basin. The Gippsland Basin bioregion encompasses the part of the onshore geological Gippsland Basin, east of the drainage divide on the Narracan Block, approximately 14,636 km^2.

The Gippsland Basin began to form in the Late Jurassic in response to rifting of the Australian plate at its southern margin (e.g. Norvick et al., 2001). Significant subsidence began in the Early Cretaceous and continued into the Cenozoic, leading to accumulation of up to about 12 km of Cretaceous and Cenozoic sediments in the main depocentres, located in the offshore portion of the basin. Deep extensional faults segment the basin into platforms and terraces with sedimentary thickness markedly increasing toward the offshore Central Deep (Rahmanian et al., 1990). Paleozoic rocks form the basement of the Gippsland Basin, mostly Ordovician to Early Devonian sandstone and shale sequence (turbidites), and are intruded by high level Middle Devonian granites (Webb et al., 2011).

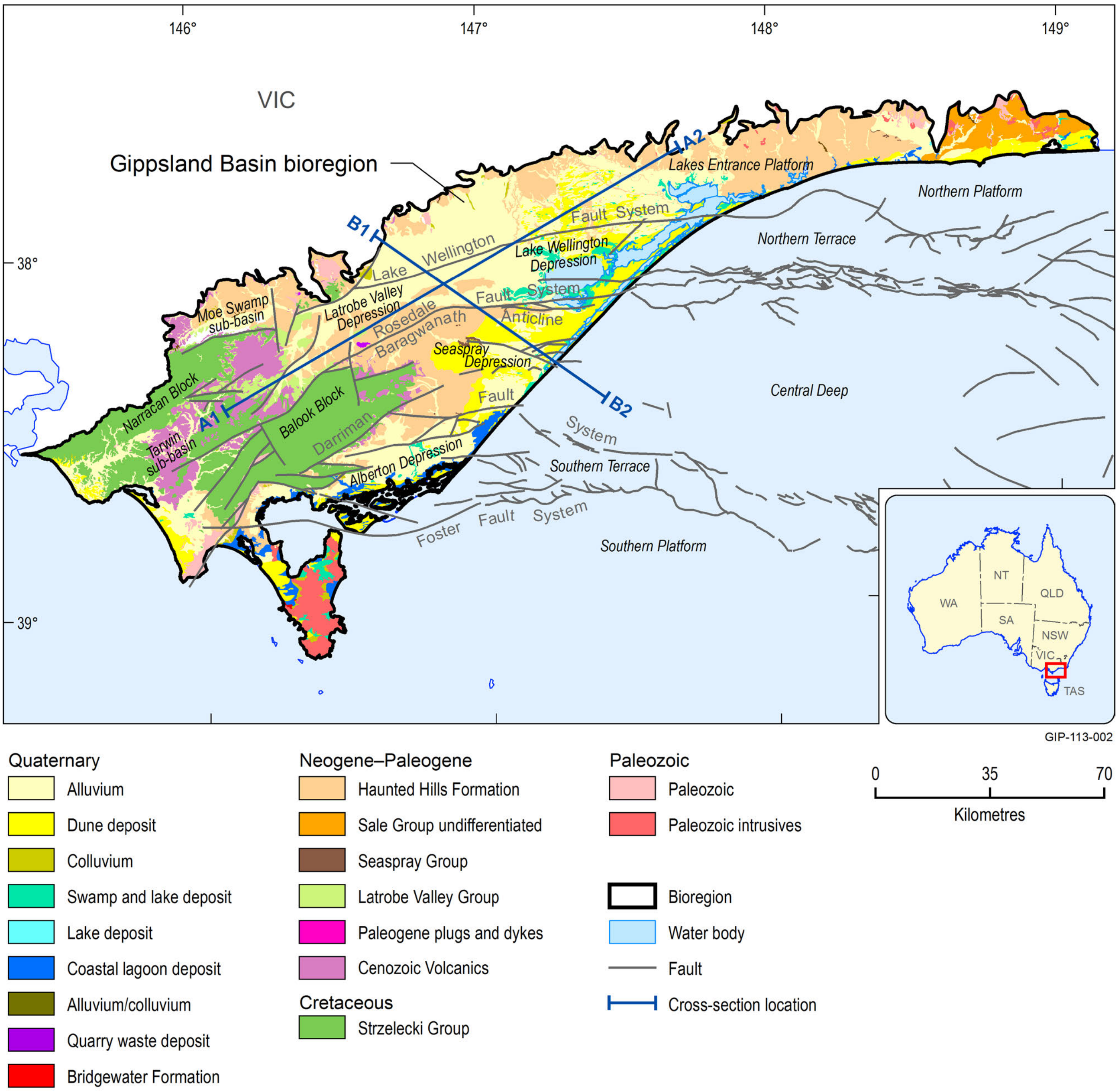

Figure 17 Geology of the Gippsland Basin bioregion including faults and structural elements. Locations of cross-sections A1–A2 and B1–B2 are delineated

Data: Department of Environment and Primary Industries (Dataset 1)

1.1.3.1.2 Structure and sub-basins

The onshore Gippsland Basin is divided into numerous structural elements. These include the Latrobe Valley Depression, Baragwanath Anticline, Seaspray Depression, Alberton Depression, Moe Swamp sub-basin, Lakes Entrance Platform and the Lake Wellington Depression (Hocking, 1976b). These subdivisions have an important control for coal resource distribution and the hydrogeology of the basin, affecting the depositional and erosional history of the basin. They will be referred to extensively throughout the remainder of this section and Section 1.1.4. Offshore, the basin has three major structural elements: the principal basin depocentre of the Gippsland Basin – the Central Deep; flanked in turn by the Northern and Southern terraces (formerly known as the Strzelecki terraces) and the Northern and Southern platforms as shown in Figure 17. The deep water part of the offshore basin (where the water column is greater than 500 m) is poorly defined and will not be discussed further in this report as it is not directly relevant to the Gippsland Basin Bioregional Assessment.

Principal fault trends are dominantly west-north-west in the offshore part of the basin, with fold trends orthogonal at north-east to east-north-east directions (Power et al., 2001). Onshore fold trends tend to align north-north-east to east-west. Significant faulting (mainly reverse) at depth in the onshore part of the basin is commonly expressed in the Eocene to Miocene aged sediments by monoclinal folding and Pliocene topographic uplift (Holdgate and Gallagher, 2003).

The key regional geological structures in the basin are the east-west extensional faults, the Lake Wellington Fault System, Foster Fault System, Darriman Fault System, Rosedale Fault System and the Baragwanath Anticline (see Figure 17). Brief descriptions of these structures are below, with further context including their influence on basin development provided in Section 1.1.3.1.2. There are many more geological structures that are important at local scales within the basin. In the Latrobe Valley Depression the depth to coal and coal seam thickness is greatly influenced by structure, for example penecontemporaneous sediment deposition, erosion and uplift have caused thick coal development over the Loy Yang Dome at shallow depths. Most outcrops of basement rocks are bounded by major faults and commonly form prominent scarps for example, the Strzelecki Group Balook Block is bounded by a number of major faults, including the Budgeree, Balook, Carrajung and Yarram faults (Hocking, 1976b).

Not all these structures are relevant to this analysis, and only those most relevant are described herein. However, the reader is referred to the publications cited throughout for more detail, in particular Bernecker et al. (2003), Cupper et al. (2003), Duddy (2003), Hocking (1976a), Holdgate (2003), and Holdgate and Gallagher (2003).

Onshore structural elements

Lakes Entrance Platform: The Lakes Entrance Platform extends across the northern Gippsland Basin (see Figure 17). It is bounded to the north by outcropping Paleozoic basement and to the south by the Lake Wellington Fault System. Offshore, it merges with the Northern Platform. Rocks of the Strzelecki Group were mostly stripped from the Lakes Entrance Platform by erosion following uplift in the Early Cretaceous. It is unconformably covered by Cenozoic undifferentiated Latrobe Group sediments, by the Seaspray Group and by thin upper Pliocene to Quaternary sediments of the Sale Group.

Latrobe Valley Depression: The Latrobe Valley Depression lies between the Eastern Highlands (Paleozoic rocks) to the north and the Lower Cretaceous Balook Block to the south (Thomas and Baragwanath, 1949). To the west it is separated from the Moe Swamp sub-basin by the Yallourn Monocline. The Depression contains up to 700 m of Latrobe Group sediments (Abele, 1988).

Baragwanath Anticline: The Baragwanath Anticline is a complex, east-plunging, uplifted structural block with some faulted margins and a number of east-north-east trending subsidiary anticlines and synclines. It forms an anticlinal axis between the Gormandale Syncline extension and the Merrimans Creek Syncline and separates the Lake Wellington Depression to the north from the Seaspray Depression to the south. The core of the structure is the Lower Cretaceous Baragwanath Block which is a buried, down faulted, eastern extension of the outcropping Balook Block (Hocking, 1976b). The Baragwanath Anticline is of Cenozoic age and is the largest anticline structure within the onshore part of the basin. It is overlain by thin Latrobe Group sediments, deposited contemporaneously with uplift (Nahm, 2002).

Lake Wellington Depression: The Lake Wellington Depression (Hocking and Taylor, 1964) is bounded by the Lakes Entrance Platform to the north (along the Lake Wellington Fault System) and the Baragwanath Anticline and Rosedale Fault System to the south. It contains the upper part of the Latrobe Group, resting unconformably on the Strzelecki Group and is overlain by marine sediments of the Seaspray Group and the younger non-marine Boisdale Formation. Total thickness of Cenozoic sediments is about 1200 m. The western boundary of the Lake Wellington Depression coincides with the limit of marine sedimentation within the Gippsland Basin. In the east, the Lake Wellington Depression merges with the Latrobe Valley Depression (Abele, 1988).

Seaspray Depression: The Seaspray Depression is bounded to the north by the Baragwanath Anticline and the Rosedale Fault System, to the west by the Balook Block and to the south by the Darriman Fault System (Hocking, 1976b). The Seaspray Depression merges offshore with the Central Deep. Cenozoic sediments have a maximum thickness about 1700 m in the Seaspray Depression, in the vicinity of the town of Seaspray (Abele, 1988).

Alberton Depression: The Alberton Depression is bounded to the north by the Yarram Monocline and the Darriman Fault System and to the south by the Foster Fault System. The Alberton Depression merges offshore with the Southern Terrace. Onshore, Cenozoic sediments may exceed 500 m thickness in the western part of the depression (Abele, 1988).

Moe Swamp sub-basin: The Moe Swamp sub-basin is at the north-western extremity of the Gippsland Basin between the Warragul and Haunted Hill Blocks (Hocking, 1976b). It is bounded by Paleozoic bedrock in the north, the Darnum Fault to the west, the Yarragon Monocline to the south and the Yallourn Monocline to the east (Brumley and Holdgate, 1983). The Cenozoic sedimentary sequence is up to 500 m thick in the Moe Swamp sub-basin (Nahm, 2002).

Tarwin sub-basin: The Tarwin sub-basin is located west of the Balook Block. It is bounded by uplifted Strzelecki Group rocks and to the north by the Narracan Block. Around 150 m of Cenozoic sediments occur in the Tarwin sub-basin.

Major regional faults

Lake Wellington Fault System and Foster Fault System: These fault systems began developing during the first phase of rifting in the Late Jurassic to Early Cretaceous. The Lake Wellington Fault System (Stainforth, 1984) is an east trending normal (extensional) fault system, mapped onshore from near Yallourn to Lakes Entrance, where it continues offshore. The Foster Fault System (Milliken, 1968) is also an east trending normal (extensional) fault system, mapped onshore near Yarram and extending offshore.

Compressional movement along these faults occurred during the Eocene (Duddy, 2003), leading to uplift of the Lakes Entrance Platform and the Southern Platform.

Darriman Fault System and Rosedale Fault System: A second phase of rifting from the Late Cretaceous to Eocene formed the Darriman and Rosedale Fault Systems. This rifting phase accommodated deposition of the Latrobe Group. The Darriman and Rosedale Fault Systems are both normal (extensional) faults. The Darriman Fault System (Maung, 1989) is generally east trending and is mapped from the southern margin of the Balook Block, across the northern extent of the Alberton Depression and extending offshore. The Rosedale Fault System (Hocking, 1976b) is east trending, mapped from the Baragwanath Anticline and extends offshore to the east.

Figure 18 and Figure 19 show two schematic geological cross-sections of the Gippsland Basin. The locations of the cross-sections are shown in Figure 17.

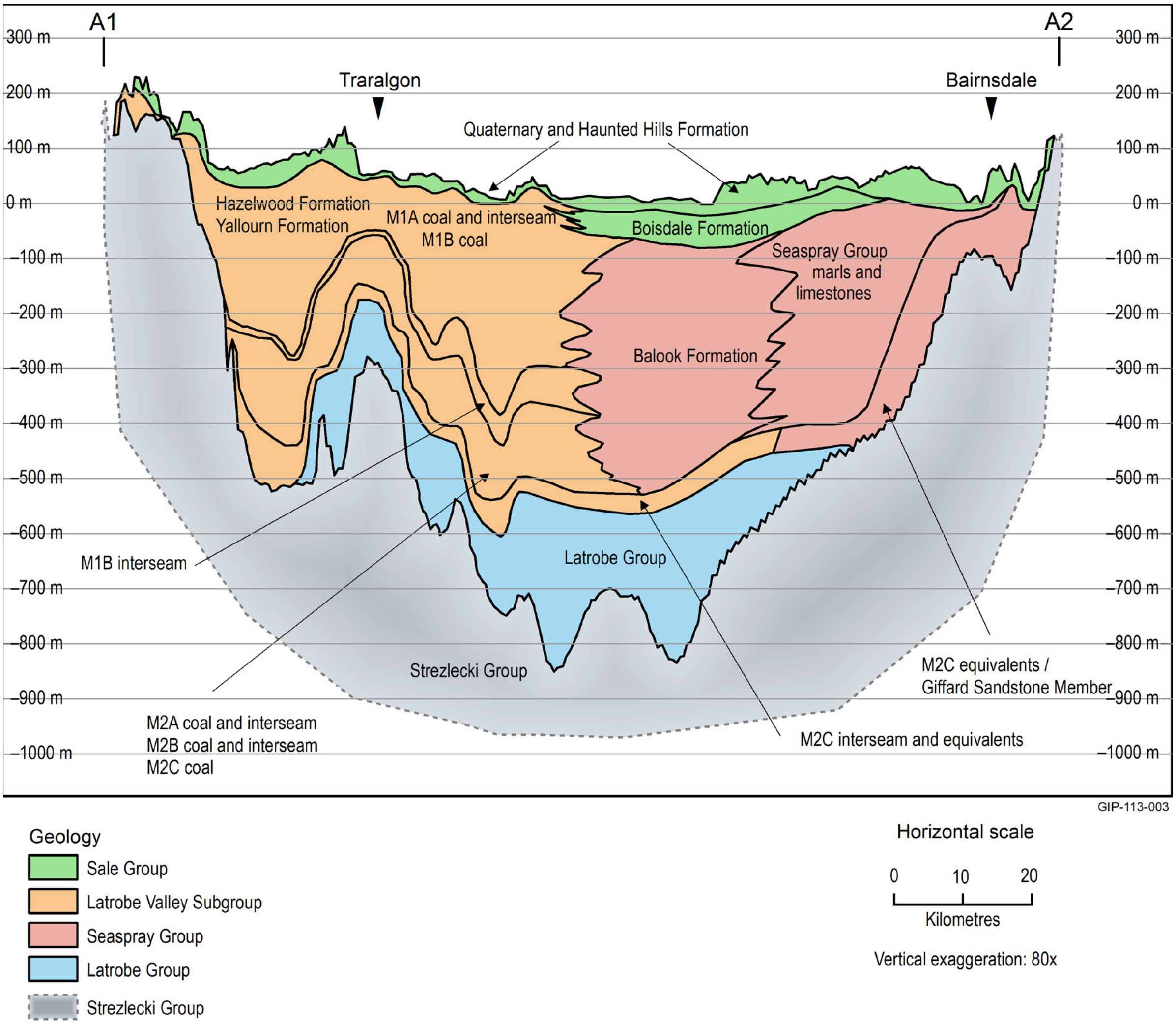

Figure 18 Schematic geological cross-section (A1–A2) of the Gippsland Basin showing the major geological unit groupings

Source: Nicol (2010)

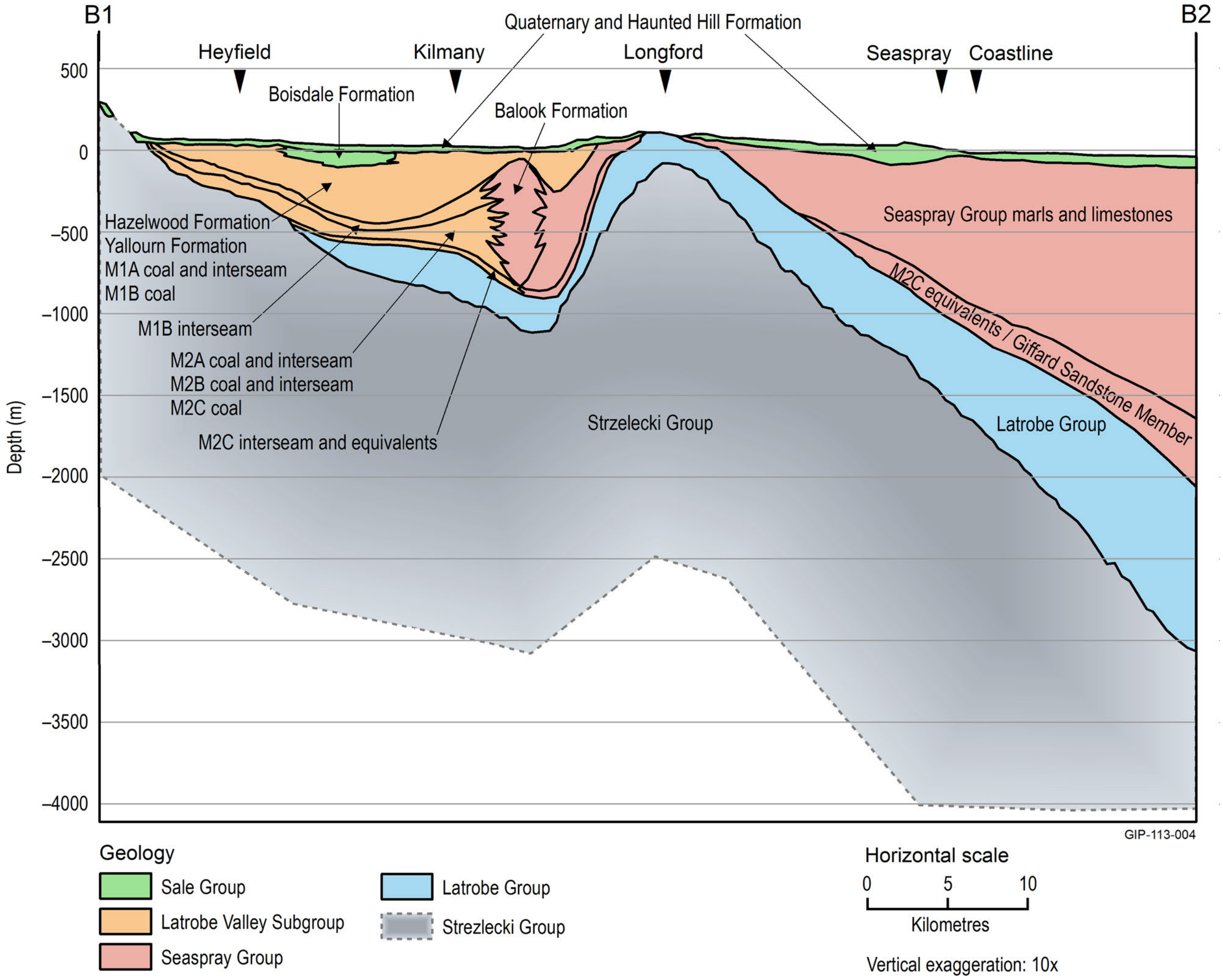

Figure 19 Schematic geological cross-section (B1–B2) of the Gippsland Basin showing the major geological unit groupings

Source: Nicol (2010)

1.1.3.2 Stratigraphy and rock type

Within the Gippsland Basin there are three major stratigraphic groups: the Early Cretaceous Strzelecki Group, the Late Cretaceous to Eocene Latrobe Group and the Oligocene to Pliocene Seaspray Group. Deposition of each of these groups was preceded by a major tectonic event resulting in erosional unconformities that define the base of each group and are presumed to be continuous across the basin (Bernecker et al., 2003).

The Gippsland Basin has a complex stratigraphy as shown in Figure 20 with lithological variation evident across the structural elements of the basin. Detailed descriptions of the stratigraphic units of the Gippsland Basin can be found in Cupper et al. (2003), Duddy (2003), Goldie Divko et al. (2009), Holdgate (2003) and Holdgate and Gallagher (2003). A summary of the stratigraphy from oldest to youngest is provided herein, focusing on the stratigraphic units of the onshore portion of the basin in the Latrobe Valley and Seaspray Depression.

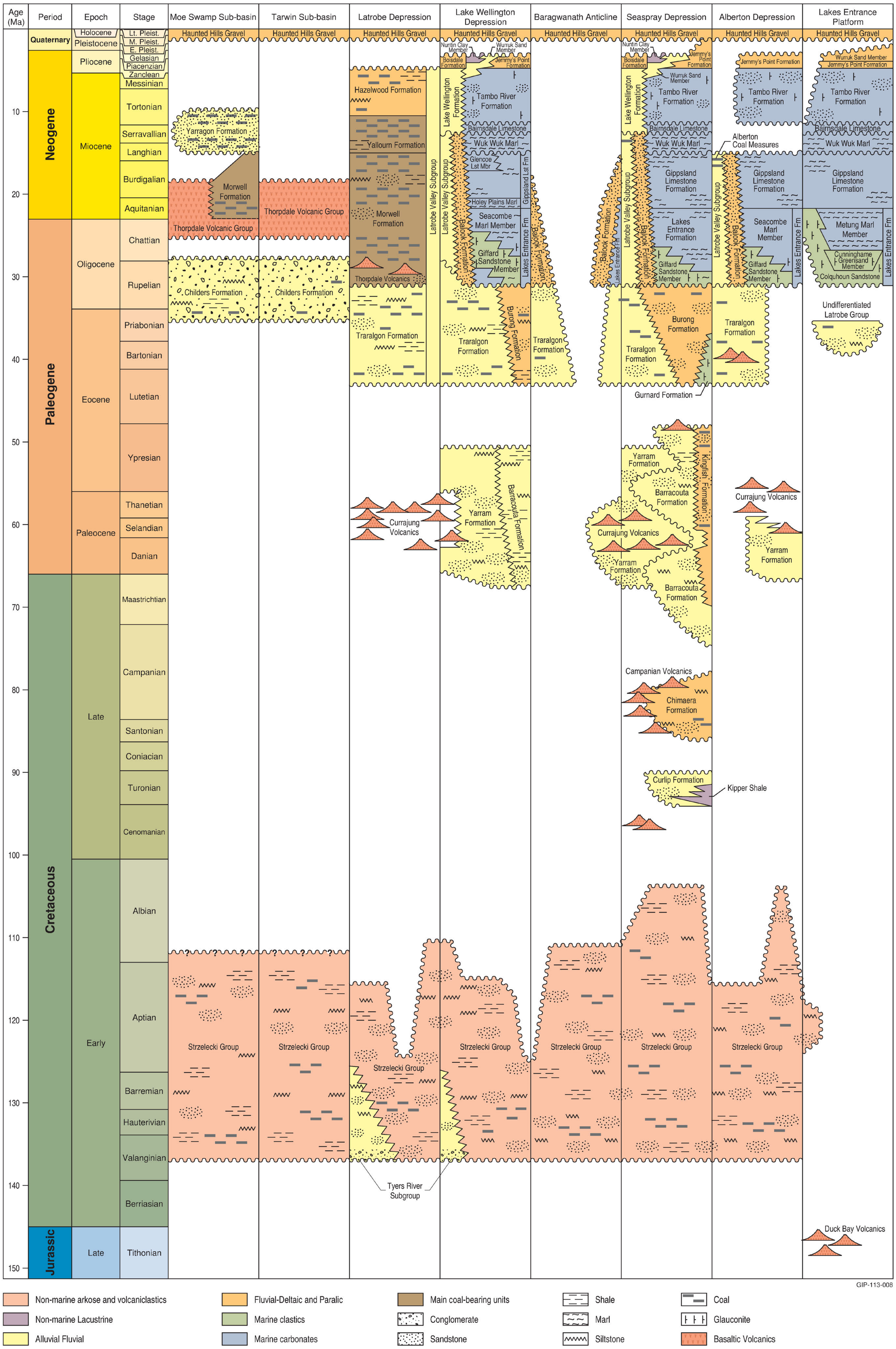

Figure 20 Gippsland Basin onshore stratigraphy

Source: Adapted from Goldie Divko et al. (2009), drawing on information from Pratt (1985), Brumley and Holdgate (1983)
Note: This figure has been optimised for printing on A3 paper (297 mm x 420 mm)

1.1.3.2.1 Strzelecki Group

The Strzelecki Group consists of non-marine Lower Cretaceous sedimentary rocks. The Strzelecki Group outcrops extensively in the South Gippsland highlands and along coastal sections between San Remo and Inverloch in South Gippsland.

Tyers River Subgroup and undifferentiated Lower Strzelecki Group

The Tyers River Subgroup outcrops in the Tyers River – Boola Boola Forest area in Gippsland Basin (formerly Tyers Group of Philip (1958)). Onshore, the Tyers River Subgroup occurs within the Latrobe Valley Depression and the Lake Wellington Depression (Goldie Divko et al., 2009).

The Tyers River Subgroup was deposited in fluvial environments grading from proximal alluvial fans of the Tyers Conglomerate to more distal fan and fluvial environments, including braided stream channels (Tosolini et al., 1999). The sediments are thought to consist of detritus largely derived from local erosion of adjacent Paleozoic rock. The basal Tyers Conglomerate is characterised by conglomerate beds with interbedded pebbly sandstone layers and rare siltstone and shale. The Locmany Member consists of upwards-fining sequences grading from a conglomeratic base through fine to medium-grained sandstone, siltstone, and in places with thin coal seams towards the top. The Exalt Member gradationally overlies the Locmany Member and is mainly an upward coarsening sandstone (Tosolini et al., 1999).

The Tyers River Subgroup is thought to correlate with a 5 km thick sequence of undifferentiated Lower Strzelecki Group rocks identified from seismic surveys in the main offshore depocentres (Duddy, 2003).

Undifferentiated Upper Strzelecki Group

Lower Cretaceous sedimentary rocks referred to as the Upper Strzelecki Group outcrop extensively in the Strzelecki Ranges. The Upper Strzelecki Group is considered to both overlie and intertongue with the Tyers River Subgroup. The sediments were originally deposited in fluvial environments dominated by internally braided channels flowing through extensive floodplains with marginal alluvial fans. Rapid subsidence led to accumulation of multi-storied channel complexes, with numerous erosion surfaces (Duddy, 2003). The sediments were mainly reworked tuffaceous material from rift-related explosive volcanism roughly contemporaneous with deposition, as well as some detritus from nearby outcropping Paleozoic rocks. The sequence exceeds 3 km in thickness and covers at least 30,000 km^2 (Duddy, 2003).

The Upper Strzelecki Group rocks are relatively uniform, consisting of a generally upwards-fining sequence of massive coarse- to fine-grained sandstone. These interfinger with a range of minor rock types including siltstone, fine-grained sandstone, paleosoils, coal seams and lacustrine shale.

In the Tarwin sub-basin, the Strzelecki Group is alternatively called the Wonthaggi Formation which bears black coal deposits that were an important coal resource in the early history of Victorian coal development.

1.1.3.2.2 Latrobe Group

Strzelecki Group deposition terminated abruptly at the end of the Albian (around 100 Ma) by significant localised uplift and erosion of Paleozoic basement at the basin margins and partial basin inversion. This formed the Otway Unconformity. Where fully developed, the unconformity separates deeply eroded Strzelecki Group rocks or Paleozoic basement from the overlying Latrobe Group (Duddy, 2003).

There are four subgroups within the Latrobe Group, each of which is bound by basin-wide unconformities. Formations in each subgroup are distinguished according to their main depositional facies assemblages (Bernecker et al., 2003).

Emperor Subgroup

The Emperor Subgroup (Bernecker and Partridge, 2001) is generally restricted to the offshore part of the basin. Onshore, the Emperor Subgroup occurs only in the Seaspray Depression. It was originally deposited in lacustrine and fluvial environments and comprises sandstone and minor lacustrine mudstone formed during the Turonian (around 94 to 90 Ma). The Emperor Subgroup has only been intersected in drill-holes around the basin margins near bounding faults of the Northern and Southern terraces.

The Emperor Subgroup is separated from the overlying Golden Beach Subgroup by the Longtom Unconformity, a sedimentary hiatus of about 3 million years duration (from around 89 Ma).

Golden Beach Subgroup

The Golden Beach Subgroup was deposited around 87 to 73 Ma (Duddy, 2003). Onshore, the Golden Beach Formation occurs only in the Seaspray Depression, where it is represented by the fluvial-deltaic Chimaera Formation (Bernecker and Partridge, 2001). The Chimaera Formation comprises coarse-grained sediments as well as fine-grained floodplain deposits including some coal and can exceed 300 m in thickness (Bernecker et al., 2003). Offshore, the Golden Beach Subgroup also contains several basaltic lava flows, scoria cones and ring-dyke intrusions (Duddy, 2003). These volcanics terminate the Golden Beach Subgroup and signal a depositional hiatus of about 2 million years represented by the Seahorse Unconformity.

Halibut Subgroup, Yarram Formation and Carrajung Volcanic Group

The Halibut Subgroup was deposited between 75 to 45 Ma. Halibut Subgroup sediments document the changes from non-marine to marine environments in a west-east, or onshore-offshore direction (Bernecker et al., 2003). Two formations are identified within the onshore part of the Gippsland Basin: the Barracouta Formation (identified in the Seaspray Depression and the Lake Wellington Depression) and the Kingfish Formation, identified in the Seaspray Depression (Bernecker and Partridge, 2005). The Barracouta Formation was deposited on an upper coastal plain and is characterised by fluvial siltstone, sandstone and minor coal. The Kingfish Formation was deposited on a lower coastal plain and sandstone, siltstone and coal were deposited in fluvial-deltaic and paralic settings (landward side of the coast).

The Yarram Formation is equivalent to the Halibut Subgroup in age. It is comprised of a sequence of fluvial/alluvial conglomerates, sandstones, thin coal and shale. The Yarram Formation occurs within the Lake Wellington Depression, Seaspray Depression and Alberton Depression.

The Carrajung Volcanic Group has been dated as 57 to 55 Ma and is comprised of tuff and basalt that can be over 100 m thick (Holdgate and Gallagher, 2003). The Carrajung Volcanic Group has been identified in the Latrobe Valley Depression, Lake Wellington Depression, Seaspray Depression and Alberton Depression.

Cobia Subgroup, Traralgon Formation and undifferentiated Latrobe Group

The Cobia Subgroup is represented onshore by the Burong Formation and the Gurnard Formation. The Burong Formation is also called the Traralgon Formation. In the coal literature, the Traralgon Formation is the name used and so the rest of this report will use Traralgon Formation. The Gurnard Formation is identified within the Seaspray Depression. The Gurnard Formation consists of fine- to medium-grained glauconitic siliciclastic rocks deposited in a shallow to open marine environment during the early Oligocene to middle Eocene.

The Traralgon Formation of the Latrobe Valley Depression, Lake Wellington Depression, Seaspray Depression and the Alberton Depression, and the undifferentiated Latrobe Group of the Lakes Entrance Platform, are age equivalents of the Cobia Subgroup. The Traralgon Formation is absent from the Moe Swamp and Tarwin sub-basins.

The Traralgon Formation is early Eocene to early Oligocene in age and was deposited in alluvial-fluvial environments. The Traralgon Formation comprises coals with interbedded gravels, sands and clays. The formation primarily comprises sands and gravels towards its base, coal seams and clays in its middle sequence, and sand, clay and minor coal in the upper sequence. The formation has been subdivided into the T1 (upper) and T2 (lower) coal seams and interseams (Holdgate et al., 2000). In the Seaspray Depression, the T2 interseam is called the Yarram Formation (Nicol, 2010).

Deposition of the Cobia Subgroup ceased during the early Oligocene. This break in sediment deposition is known as the Latrobe Unconformity (Bernecker et al., 2003).

1.1.3.2.3 Seaspray Group

The Seaspray Group and the main coal-bearing units of the Latrobe Valley Subgroup began to form during the early Oligocene. By the Oligocene, most of the basin had become marine in character. Exceptions to this occur in the Latrobe Valley, Baragwanath Anticline and Alberton Depression where non-marine Morwell and Yallourn Formation coal sequences continued to accumulate behind sand barrier systems (Balook Formation) (Holdgate et al., 2000). The Latrobe Valley Subgroup coal-bearing formations are a non-marine facies equivalent to the Seaspray Group further east (Holdgate and Gallagher, 2003).

Within the Latrobe Valley Depression, the Morwell Formation, Yallourn Formation and Hazelwood Formation are grouped together as the Latrobe Valley Group.

Across the onshore part of the basin the following trend from non-marine to marine sediments is evident:

- In the east (near Orbost) and the south, the system is dominated by marine rocks, limestones and marls of the Seaspray Group.
- Heading west and north, towards the Latrobe Valley Depression, the sandstone of the Balook Formation (deposited as barrier sands) dominates the system.
- Heading further west and north into the Latrobe Valley Depression, alluvial and fluvial sediments, sandstones, coal, siltstones and shales dominate.

Lakes Entrance Formation

The Lakes Entrance Formation comprises the earliest fully marine sediments in the onshore Gippsland Basin and was deposited during the late Oligocene and early Miocene (Holdgate and Gallagher, 2003; Thompson and Walker, 1982). Onshore, the Lakes Entrance Formation includes the Giffard Sandstone Member, Cunningham Greensand Member, Metung Marl Member and the Seacombe Marl Member (Hocking, 1976a). The formation continues offshore where it is considered an important regional seal over most of the oil and gas fields, reaching a maximum thickness of 500 m (Holdgate and Gallagher, 2003).

Gippsland Limestone

The increasing dominance of marine conditions during the late Oligocene and early Miocene resulted in the deposition of marl and shelf carbonates. The Gippsland Limestone of early Miocene age was deposited in cold water at mid- to outer-shelf depths and consists of a thick sequence of carbonates that overlies the Lakes Entrance Formation both onshore and offshore (Holdgate and Gallagher, 2003). The Gippsland Limestone has maximum thickness of around 240 m in the eastern part of the Lake Wellington Depression.

Wuk Wuk Marl

The Wuk Wuk Marl was deposited in the middle Miocene into a high-productivity, upwelling, warmer water environment. It overlies the Gippsland Limestone east of the Baragwanath Anticline (Holdgate and Gallagher, 2003).

Balook Formation

The Balook Formation formed in a depositional transition zone, between the mostly terrestrial sequence in the west and north, and the marine sequence in the south and east. The formation is a barrier sand sequence and lies immediately inland of the Seaspray Group. It consists of about 400 m of fine- to medium-grained sand with minor interspersed clayey and lignitic horizons (Thompson and Walker, 1982). The formation extends north-north-east for 150 km across the Seaspray and Lake Wellington depressions. However, it is not present across the Baragwanath Anticline and associated structures (Nicol, 2010). The Balook Formation formed the coastal barrier behind which the coals of the Latrobe Valley Subgroup accumulated and includes all the transgressive sand beds in the Latrobe Valley Coal Measures (Holdgate and Gallagher, 2003).

Bairnsdale Limestone

The Bairnsdale Limestone overlies the Wuk Wuk Marl. It was deposited in the middle Miocene. It is a relatively thin unit with a maximum thickness of about 25 m (Holdgate et al., 2003), consisting of marl and calcarenite (Geoscience Australia, 2012).

Tambo River Formation

The Tambo River Formation comprises strandplain sediments of glauconitic sandy coquina limestone deposited in the middle Miocene. It conformably overlies the Bairnsdale Limestone (Holdgate and Gallagher, 2003), and is a regressive sequence representing transition between the Bairnsdale Limestone and the Jemmys Point Formation. The subsurface thickness averages 33 m in the Seaspray Depression and is up to 100 m in the western part of the Lake Wellington Depression (Abele, 1988). The maximum thickness is 300 m (Geoscience Australia, 2012).

Lake Wellington Formation

The middle Miocene marine regression resulted in deposition of the Lake Wellington Formation, deposited as lacustrine facies up to 90 m thick in locally depressed areas within the Seaspray and Lake Wellington depressions. The formation is described as fine uniform silty sand which exhibits rhythmic bedding or coarser non-calcareous sands (Thompson and Walker, 1982).

Jemmys Point Formation

The Jemmys Point Formation was deposited as the result of a relatively short lived marine transgression during the early Pliocene. It is subdivided into three members: the (lower) Tarraville Member which is up to 20 m thick and consists of dark lagoonal bioturbated muds and clays, the (upper) Tarraville Member which is up to 100 m thick and consists of fine to medium-grained quartz sands, and the Woranga Member which consists of a thin marly limestone to shelly sand (Thompson and Walker, 1982).

Thorpdale Volcanic Group

The basaltic Thorpdale Volcanic Group outcrops extensively in the South Gippsland highlands and has a maximum thickness of around 60 m over the Narracan, Warragul and western Balook Blocks (Holdgate and Gallagher, 2003). Volcanism occurred from the Eocene to the Miocene (49 to 22 Ma) (Australian Stratigraphic Units Database, 2012). Basaltic sills extend from the major eruptive centres and locally interbed and underlie the Morwell Formation within the Latrobe Valley Depression.

Morwell Formation

The Morwell Formation is a complex unit of thick coal seams and lesser clay and sand that disconformably overlies the Traralgon Formation in the Latrobe Valley Depression, deposited during the Oligocene and early Miocene (Holdgate, 2003). The Morwell Formation, together with the similar-aged Alberton Formation (located in the Alberton Depression, south of the Baragwanath Anticline) are confined to the part of the Gippsland Basin that is west of the Balook Formation, the sand barrier that marks the predominant maximum point of marine transgression for the Seaspray Group. The Morwell Formation extends across the Latrobe Valley Depression and grades into the Thorpdale Volcanic Group in the Moe Swamp sub-basin and on the Narracan Block. The lateral marine equivalents of the Morwell and Yallourn formations are the Lakes Entrance Formation and Gippsland Limestone.

The Morwell Formation has been subdivided into several coal seam and interseam units, namely, the M2C, M2B, M2A, M1B and M1A coals and interseam sediments (listed from oldest to youngest). The formation is locally interbedded with and underlain by the Thorpdale Volcanic Group. The Childers formation, in the Moe Swamp and Tarwin sub-basins, is equivalent to the Lower Morwell Formation (M2) of the Latrobe Valley.

Yallourn Formation

The Yallourn Formation was deposited in the middle Miocene. It consists mainly of the Yallourn Coal Seam (and its subseams Y1–Y4) and conformably overlies the Morwell Formation. In the Latrobe Valley, the Yallourn and Morwell coal seams are separated by the Yallourn Clay which is up to 5 m thick (Holdgate, 2003). Similar to the Morwell Formation, the Yallourn Formation grades laterally eastwards into the Balook Formation. In the adjacent Moe Swamp sub-basin to the west, an isolated coal-bearing sequence of equivalent age to the Yallourn Formation is known as the Yarragon Formation. The Yallourn Formation is absent from the Tarwin sub-basin.

The Yallourn Coal Seam has been subsequently modified by late Miocene erosion to a greater extent than the coal seams of the Morwell Formation.

Hazelwood Formation

The non-marine Hazelwood Formation was deposited during the late Miocene. This is a clay-rich coaly unit up to 200 m thick, predominantly within the Traralgon and Latrobe synclines in the Latrobe Valley Depression (Holdgate, 2003). The Hazelwood Formation grades into the marine Lake Wellington Formation, Tambo River Formation and Bairnsdale Limestone.

1.1.3.2.4 Sale Group

The Sale Group consists of marine to non-marine sediments deposited during the Pliocene to Pleistocene.

Boisdale Formation

The Boisdale Formation unconformably overlies the Lake Wellington Formation and is found from east of Rosedale to the Lakes Entrance area, and in the onshore Seaspray Depression (Nicol, 2010). It is a terrestrial (fluviatile) sequence that primarily comprises sand, silt and clay. It has been divided into two sub-units, namely the (lower) Wurruk Sand Member and the (upper) Nuntin Clay Member. Along the coastline, the formation transitions into and partly overlies its marine equivalent, the Jemmys Point Formation. The Boisdale Formation was deposited during the late Miocene to early Pliocene (HydroTechnology, 1994; Nicol, 2010).

Haunted Hills Gravel

A major marine regression during the Pliocene resulted in deposition of river gravels and alluvium known as the Haunted Hills Gravel (Holdgate and Gallagher, 2003; Thompson and Walker, 1982).

The formation has a wide range of particle sizes, generally poor sorting, variable bedding, and widespread lensing with numerous local erosional breaks. The Haunted Hills Gravel consists of sand, gravel and clay with a maximum thickness of around 30 m (Abele, 1988).

1.1.3.2.5 Quaternary

Quaternary depositional environments in the Gippsland Basin are significantly different from those of the Paleogene and Neogene carbonate, siliciclastic and lignitic sedimentation (Cupper et al., 2003). Quaternary sediments are mostly undifferentiated and unconsolidated alluvium restricted to the floodplains of the main waterways and drainage features. Minor lacustrine, swamp and dune sand deposits also occur. The Quaternary sediments generally form a thin cover over the Haunted Hills Gravel. In some areas there are thicker Quaternary sediments where paleochannels of the present-day Snowy, Nicholson/Tambo, Mitchell, Avon/Perry and Thompson/Macalister/Merrimans Rivers, and Ironstone Creek deposited sand, gravel, clay and silt during glacial lowstands of the early to middle Pleistocene (Cupper et al., 2003).

1.1.3.3 Basin history

Late Jurassic to Early Cretaceous

In the Late Jurassic to Early Cretaceous, a series of east oriented grabens developed across the southern margin of Australia, during the initial stages of rifting between Australia and Antarctica (Duddy, 2003; Webb et al., 2011). Subsidence, accommodated by crustal extension, resulted in the deposition of the Strzelecki Group in the Gippsland Basin. During the middle Cretaceous, the rift between Australia and Antarctica moved to the south of Tasmania as the Southern Ocean began opening (Webb et al., 2011). The eastern part of the original graben remained active as the Gippsland Basin (Duddy, 2003; Webb et al., 2011). A phase of compression near the beginning of the Late Cretaceous (about 96 Ma) was associated with the breakup of Australia and Antarctica (Chiupka, 1996). This resulted in development of elevated regions along the basin margin referred to as the Lakes Entrance and Southern platforms. Extensive erosion of Strzelecki Group rocks occurred following this uplift (Chiupka, 1996) producing a major unconformity in the Gippsland Basin known as the Otway Unconformity (Duddy, 2003). Uplift during this time is thought to have been accompanied by a major thermal event that strongly influenced the rank of the Strzelecki Group coals (Holdgate, 2003).

Late Cretaceous to Late Eocene

During the Late Cretaceous, the central part of the basin subsided rapidly, resulting in the deposition of the Latrobe Group in the now offshore part of the basin.

Early normal displacement along the Rosedale and Darriman faults (regional east-west trending intrabasinal elements) occurred during a second phase of rifting near the middle of the Late Cretaceous (80 Ma). This was associated with the Australia/Lord Howe Rise separation and opening of the Tasman Sea (Duddy, 2003; Goldie Divko et al., 2009) and led to development of the Northern and Southern Strzelecki Terraces (Goldie Divko et al., 2009).

Lower rates of subsidence continued across the onshore basin from the end of the Cretaceous to the late Eocene (65 to 35 Ma) accommodating further deposition of Latrobe Group sediments.

Late Eocene to Late Miocene

A major basin-wide compressional event is believed to have occurred during the late Eocene to early Miocene that caused many of the structural features evident today and terminated deposition of the Latrobe Group. Compressional uplift during this time is evident in the present landscape as the uplifted fault blocks of the Lower Cretaceous (Strzelecki Group) South Gippsland highlands including the Balook, Gelliondale, Tarwin, Narracan and Warragul blocks that form the westerly basin limits (Holdgate and Gallagher, 2003). All major fold structures at the top of the Latrobe Group, which became hosts for the large offshore oil and gas accumulations, relate to late Eocene to Miocene tectonism (Geoscience Australia, 2014).

During the Cenozoic, the Gippsland Basin underwent a gradual transition from essentially non-marine to more marine as a result of the opening of the Southern Ocean during the Late Cretaceous (Holdgate and Gallagher 2003). During the Neogene (Miocene-Pliocene), the Gippsland Basin was predominantly marine with deposition of limestones and marls of the Seaspray Group. However in some areas, non-marine sediments accumulated behind transgressive barrier sands (Balook Formation) along a shifting shoreline (Holdgate et al., 1988). This sedimentation resulted in the deposition of the extensive coals of the Latrobe Valley Group.

During the middle to late Miocene-early Pliocene (10 to 5 Ma), north-west oriented compression associated with the Kosciuszko Uplift created the Balook Block (Webb et al., 2011). Miocene limestones thin onto highs such as the Baragwanath Anticline, indicating slow uplift contemporaneous with deposition before the Pliocene (Holdgate and Gallagher, 2003). Folding, uplift and erosion of the Latrobe Valley Group and Alberton Coal Measures is noted during this time, influencing the accessibility of brown coal resources in the basin (Holdgate et al., 2000).

Pliocene to recent

Tectonism continued to affect the basin during the late Pliocene to Pleistocene, as documented by localised uplift. A late Pliocene unconformity that correlates to the period of compression, folding, uplift and erosion is known as the Kosciuszko Uplift (Holdgate et al., 2007).

Much of south-eastern Australia is now currently under a north-north-west to south-south-east compression regime related to northward movement of the Australian Plate. Most of the onshore Gippsland Basin folds trend north-north-east, approximately at right angles to this compressional direction (Holdgate, 2003). Ongoing tectonic activity continues in the basin as relatively minor earthquakes along and around major basin bounding faults (Geoscience Australia, 2014).

In the now offshore part of the basin, the youngest carbonate facies of the Gippsland Basin date to about 0.2 Ma (Middle Pleistocene). Onshore, marine regression during the late Pliocene to early Pleistocene resulted in terrestrial siliciclastic sedimentation in a series of outwash fans, river gravels and alluvium (Cupper et al., 2003). During the early to middle Pleistocene siliciclastic sediments were deposited in fluvial-channel and estuarine environments by rivers flowing to the sea during glacial lowstands. Of particular significance are the paleochannels of the present-day Snowy, Nicholson/Tambo, Mitchell, Avon/Perry and Thompson/Macalister/Merrimans rivers, and Ironstone Creek, where thick accumulations of sand, gravel, clay and silts have deposited (Cupper et al., 2003). Offshore, paleochannels have also been identified in Pleistocene sediments using magnetic imagery (Bernecker and Partridge, 2005).

A series of sandy barrier ridges formed along the Pliocene to Pleistocene coastline of the Gippsland Basin. These barrier systems underlie the modern Gippsland Lakes and Ninety Mile Beach barrier system and extend offshore (Bernecker and Partridge, 2005). These barrier systems are now buried by more recent sediments across the basin. Erosion of these sediments onshore is evident in the area immediately south of Lakes Entrance and north-east of the Mitchell River (Cupper et al., 2003). The present-day Gippsland Lakes system formed in the late Pleistocene to Holocene behind sand barriers and dunes of the Ninety Mile Beach (Holdgate et al., 2003).

1.1.3.4 Coal and hydrocarbons

Figure 21 shows the distribution of coal, oil and gas fields of the Gippsland Basin. Multiple resources are viable for development in the Gippsland Basin including groundwater use, hydrocarbon extraction, coal mining and geological storage of carbon dioxide (CO_2) (Varma and Michael, 2012). A summary of coal, hydrocarbon and potential CO_2 reservoir resources is provided herein. Groundwater is discussed in detail in Section 1.1.4.

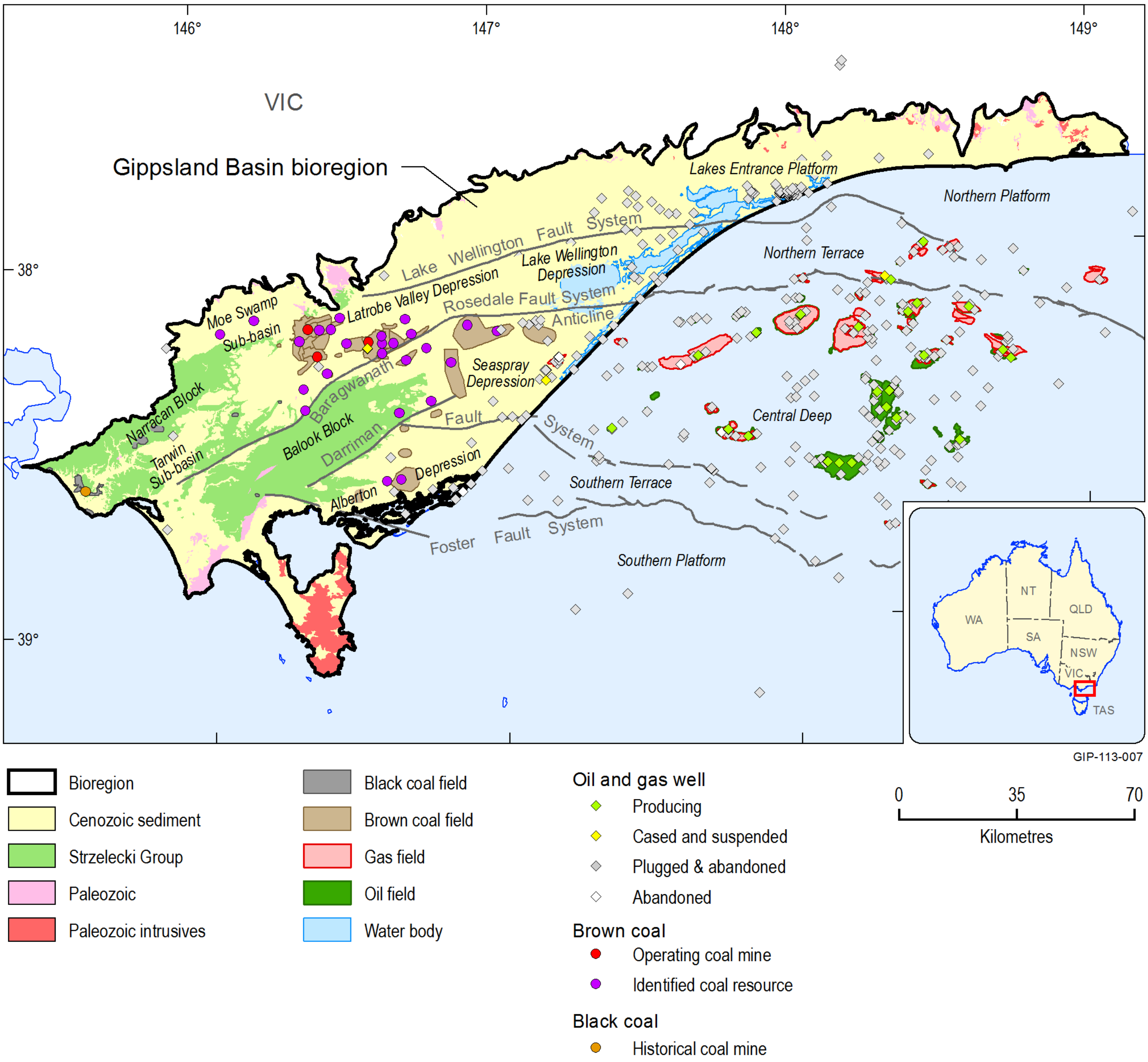

Figure 21 Distribution of coal fields and resources, oil and gas fields of the Gippsland Basin

Data: Geoscience Australia (Dataset 2), Department of State Development, Business and Innovation (Dataset 3), Department of Environment and Primary Industries (Dataset 4) Department of State Development, Business and Innovation (Dataset 5)

An overview of coal resources is provided here. More detailed discussion of coal resources in the Gippsland Basin bioregion will be presented in companion product 1.2 of the Bioregional Assessment (Coal and coal seam gas resource assessment).

Black coal

Black coal occurs within the Cretaceous Strzelecki Group of the Gippsland Basin. The coals are mainly high-volatile bituminous with 5 to 10% moisture, 30 to 35% volatile matter and 6 to 12% ash. Vitrinite reflectance is up to 0.9% Rv for buried strata, and 0.5 to 0.67% Rv for strata in outcrop (Holdgate, 2003). Some black coal production has occurred historically within the Gippsland Basin where local uplift and erosion stripped overburden. This has mainly been in the vicinity of the Narracan Block, where black coal was mined from Lower Cretaceous Strzelecki Group rocks, most notably at Wonthaggi. Mining of black coal occurred between 1864 and 1970 and production amounted to approximately 23 million tonnes (Mt) (Holdgate, 2003).

Brown coal

Brown coal deposits formed in the Gippsland Basin during the Cenozoic and are hosted within the Latrobe Group and Latrobe Valley Group. The brown coal deposits of the Latrobe Valley Depression are the largest of their type in the world (Holdgate, 2003). Currently, large scale open-cut mining occurs in the Latrobe Valley at a rate of approximately 40 Mt per year from three mines at Hazelwood, Loy Yang and Yallourn. This production supplies most of Victoria's electricity needs. Historically, small-scale brown coal mining occurred at Gelliondale (Alberton Depression) (Holdgate, 2003). Holdgate (2003) described the size of the brown coal resource of the Latrobe Valley as effectively without limit, stating:

> Whether any further future developments occur depends very much on satisfying greenhouse gas emission standards, because there are currently no limits to the economically winnable reserves, at least for many hundreds of years to come.

A detailed coal resource inventory for all of Victoria including the Gippsland Basin was undertaken in 2007 (GHD, 2007) providing an estimate of potential economic coal resources. Table 12 summarises the distribution of known brown coal resources in the Gippsland Basin.

Table 12 Brown coal fields of the Gippsland Basin

Structural Elements	Formation	Field(s)
Latrobe Valley Depression	Traralgon, Morwell and Yallourn Formations	Churchill, Driffeld, Flynn, Loy Yang Mine, Morwell, Tyers, Churchill North, Driffield East, Hazelwood Mine, Loy Yang East, Rosedale, Yallourn Mine, Corridor Field, Fernbank, Latrobe River, Maryvale East, Traralgon Creek, Yinnar
Moe Swamp sub-basin	Yarragon Formation (an isolated age equivalent unit of the Yallourn Formation)	Yarragon and deposits in the Moe Monocline area
Baragwanath Anticline	Not specified, likely Traralgon Formation	Coolungoolun, Gormandale, Longford, Stradbroke
Seaspray Depression	Sediments equivalent to the Morwell and Traralgon Formations	Alberton East, Greenmount, Boodyarn, Won Wron
Alberton Depression	Sediments equivalent to the Morwell and Traralgon Formations	Gelliondale

Data: GHD (2007)
Note there are no coal fields in the Lakes Entrance Platform or the Lake Wellington Depression, however, thin coal seams are intercepted under deep cover in boreholes within these regions)

The Traralgon Formation contains the largest brown coal deposits in the Gippsland Basin (Holdgate et al., 2000). Two coal seams are named within the Traralgon Formation, the T1 and T2 seams. Seam thicknesses often exceed 100 m. Where the seams occur in stratigraphic superposition, they form a total thickness of over 150 m.

The younger T1 seam is recognised in the Latrobe Valley Depression, north and west of the Rosedale Monocline/Fault, extending a short distance to the west of Loy Yang where the westerly limit of the T1 coal seam is controlled by the Morwell Monocline/Fault (Holdgate et al., 2000). It is present across the Baragwanath Anticline and in the Lake Wellington, Seaspray and Alberton depressions (Holdgate et al., 2000). The northern limit of the T2 coal seam is controlled by the

Rosedale Monocline/Fault. It is present on the Baragwanath Anticline, and in the Lake Wellington and Seaspray depressions (Holdgate et al., 2000). T2 coals can also extend over 25 km offshore (Holdgate et al., 2000).

Traralgon Formation coal seams near the basin margins have moisture contents around 55%. With deeper burial and folding, moisture content decreases and moistures below 50% are normally found (Holdgate et al., 2000). On average, there is a decrease of 2.7% in moisture content between the T1 and T2 seams (Holdgate et al., 2000). The coals have low ash content (mean 2.9% db). Samples collected from more deeply buried coals are generally higher in rank than those collected at more shallow depths (Holdgate et al., 2000).

The Traralgon Formation coal seams subcrop generally beneath < 30.5 m overburden across the Baragwanath Anticline uplift area where, out of an indicated resource of 345 billion tonnes (Bt) across the basin, approximately 10 Bt are considered economically recoverable reserves (Holdgate et al., 2000). Elsewhere in the basin, the Traralgon coal seams are deeply buried, for example in the Seaspray Depression they are covered by 300 to 700 m thick Seaspray Group limestones. They are unlikely to be mined in the areas of thick cover, but may constitute a possible coal seam gas resource (Holdgate, 2003).

The Morwell and Yallourn Formations of the Latrobe Valley Group host the most economic deposits of brown coal (Holdgate et al., 1995). They are located in the Latrobe Valley Depression. The Latrobe Valley Group can be up to 700 m thick, of which more than two-thirds can be brown coal. The thickness of individual seams, five of which are greater than 100 m thick, and the vertical multi-seam levels are without parallel in the world (Holdgate et al., 1995). In some areas, superposition of seams results in coal thickness in excess of 200 m, for example on the western flank of the Loy Yang Dome, the Morwell 1A, 1B and 2 seams all combine, producing up to 230 m of continuous coal (Holdgate, 2003). Around 30 Bt of economically recoverable reserves have been identified along structural highs within the Latrobe Valley Depression (Holdgate et al., 1995).

Moisture contents of the Yallourn coals range from 64.4% to 68.1% (Holdgate, 2003). Moisture contents of Morwell coals range from 54.4% to 64.6% (Holdgate, 2003). Moisture contents generally decrease with coal age and depth of burial. For any given depth, moisture content is generally higher on anticlines due to lowered intensity of compression than in adjacent synclines (Holdgate et al., 2007). Ash contents are low, ranging from 1.8% db to 3.2% db in the Yallourn coals and 1.5% db to 3.8% db in the Morwell coals (Holdgate, 2003) where ash contents are reported on a dry weight basis (db).

The Morwell 2 sequence comprises three main subseams, the M2A, M2B and M2C. In the north-western area of the Latrobe Valley, the three seams combine to form over 150 m of continuous coal (Holdgate et al., 1995). The sequence thins eastward in the down-dip directions. The Morwell 1B sequence (M1B) comprises 120 m of continuous coal (Holdgate et al., 1995). The Morwell 1A (M1A) sequence has a similar thickness to the M1B (Holdgate et al., 1995). At Loy Yang and Morwell, the M1A and M1B seams join to form over 180 m of continuous coal, while elsewhere the seams are separated by a thin marine clay. The M1A coal can be up to 100 m thick in the main coal fields, but over large areas of the central Latrobe Valley the seam splits into interbedded clay, coals and lesser sands (Holdgate et al., 1995).

The Alberton coal measures are an age equivalent of the Morwell Formation in South Gippsland. The coal seams within the Alberton coal measures are the upper A seam (55 m thick) and the lower B seam (15 m thick). They average 60% moisture content (Holdgate et al., 2007).

The Yallourn sequence comprises up to 110 m of coal in areas near the western end of the Latrobe Valley. The seam spatially overlies the Morwell 2 seam. The major Yallourn depocentre was on the downthrown east side of the Morwell Monocline (Holdgate et al., 2007). On the upthrown west side, the Yallourn sequence is truncated by Pliocene erosion. West of the Yallourn Monocline, the seam is eroded off the uplifted Haunted Hill Block. An age equivalent, the Moe Seam occurs in the Moe Swamp sub-basin, west of the Haunted Hills Block with a thickness of 40 m (Holdgate et al., 2007).

1.1.3.4.1 Geological hazards

Subsidence

Lowered artesian pressures in the aquifers of the Latrobe Valley resulting from coal mine depressurisation has caused increased effective stress within the sediments of the Latrobe Valley Group, with resulting consolidation and subsidence. These are variable due to complexities in the aquifers, aquitards and overlying sedimentary deposits (Neilson et al., 2003).

Although subsidence has not been detected along the coast of the Gippsland Basin (Department of Environment and Primary Industries, 2014; Sjerp and Charteris, 2008), predictive subsidence modelling suggests that subsidence may occur along the coast as a result of the lowering of hydraulic heads in the Latrobe Group Aquifer, caused by offshore oil and gas production, onshore groundwater extraction for irrigation and coal mine dewatering (Freij-Ayoub et al., 2007). Based on their projections of future groundwater level in the Latrobe Group Aquifer, Freij-Ayoub et al. (2007) predicted maximum coastal subsidence of between 480 and 1208 mm in the year 2056.

1.1.3.4.2 Conventional and unconventional hydrocarbons

Conventional oil and gas

The Gippsland Basin is one of Australia's major crude oil and natural gas provinces. More than 400 petroleum exploration wells have been drilled in the basin and approximately 90,000 line km of two-dimensional seismic data and more than forty three-dimensional seismic surveys have been acquired. Consequently, exploration within the basin is mature in comparison with other Australian basins, particularly in the Central Deep region of the basin. Outside this region however, the basin is relatively under-explored in comparison with other prolific hydrocarbon producing basins around the world (Geoscience Australia, 2014).

Most demonstrated oil and gas resources are in the offshore portion of the basin. Oil and gas are mainly produced from structural and structural/stratigraphic traps within the Oligocene, Eocene, Paleocene and Late Cretaceous marine, marginal marine and continental clastic sequences. Liquid hydrocarbon production peaked in 1985 and has gradually declined since then. Table 13 provides an overview of produced and remaining conventional oil and gas demonstrated resources in the Gippsland Basin. There is an expectation that further recoverable conventional gas resources will be discovered in the Gippsland Basin (Bradshaw et al., 2012; Pollastro et al., 2012).

Table 13 Gippsland Basin oil and gas resources in units of Petajoules (PJ)

	Produced (PJ)	Remaining (PJ)
Crude oil	25 536	1699
Condensate		753
LPG		646
Conventional gas[a]	8791	9300

Data: Geoscience Australia (2010), [a]Bradshaw et al. (2012)

The main period of hydrocarbon generation and expulsion is thought to have commenced in the Miocene as a result of increased sedimentary loading of the Cenozoic carbonate sequences. In the major depocentres of the basin, restricted areas underwent an earlier phase of generation and migration around the middle Eocene. At that time, no regional Lakes Entrance seal was in place and any traps would have involved older intra-Latrobe Group sealing units and earlier formed traps (Geoscience Australia, 2014).

Onshore, three sparsely explored hydrocarbon play fairways have been identified: the Early Neocomian part of the Strzelecki Group, the Golden Beach Subgroup, and the intra-Latrobe Group at target depths ranging from 800 to 4000 m (Chiupka, 1996). Table 14 is an overview of the Gippsland Basin petroleum system.

Unconventional hydrocarbons

At present, the Victorian unconventional gas industry is at a very early stage. It is not yet known whether coal seam gas extraction is economically viable in the Gippsland Basin. A moratorium on hydraulic fracturing has been in place in Victoria since August 2012 (Ross and Darby, 2013). The moratorium has slowed commercial exploration for unconventional gas resources.

Harrison et al. (2012) divided the onshore Gippsland Basin into two distinct zones that have different prospectivity for unconventional gas resources: the ‘Western Block’ where the lower rift sequence of the Cretaceous Strzelecki Group is widely exposed due to multiple episodes of basin inversion along north-easterly trending faults linked to the basement, and the ‘Eastern Depression’ where the Strzelecki Group is more simply distributed across the basement, with structure still dominated by the original east-west extensional faults.

Table 14 Gippsland Basin petroleum system

Petroleum System component	Description
Oil families	Proven Austral Petroleum Supersystem. Late Cretaceous to Eocene Austral 3 oil population. Three main oil families recognised related to stratigraphic position and in-reservoir alteration. Proven Latrobe- Latrobe system. Also minor contributions from a marine source rock interpreted for some oils.
Source	Organic-rich, non-marine, coastal plain shales and coals of the Upper Cretaceous to Late Miocene Latrobe Group (kerogen Type II/III). Richest source rocks occur within coastal plain and coal swamp facies.
Reservoir	Marine near-shore barrier and shoreface sandstones of the Top Latrobe ('coarse clastics') and intra-Latrobe fluvial-deltaic sandstones (Latrobe Siliciclastics). Sandstones in the underlying Golden Beach Subgroup and in the Gurnard Formation channel fill sands unconformably overlying the Latrobe Group.
Seal	The Seaspray Group (Lakes Entrance Formation) forms the regional seal. Intra-formational seals present within the Latrobe Group. The reservoirs of the Golden Beach Subgroup are partly sealed by younger volcanics and partly by upthrown older lacustrine shales of the Emperor Subgroup.
Traps	Anticlines, fault closures, erosional remnants, Top Latrobe subcrops.
Generation and timing	Main phase of hydrocarbon expulsion in the Neogene, with earlier phase in the Latest Cretaceous/Paleocene. Trap formation from Cenomanian through to Neogene.

Data: Geoscience Australia (2015)

Coal seam gas

Harrison et al. (2012) noted that groundwater flowing off the highlands and Strzelecki Ranges toward the petroleum production areas could be continually bringing new nutrients into Traralgon Formation coal sequences and removing wastes to enable microbial production of methane. Temperature ranges in the Traralgon Formation are close to or overlapping with the survival threshold for micro-organisms, allowing a small possibility of microbial methane production (Harrison et al., 2012). Further discussion of coal seam gas development potential will be provided in companion product 1.2 of the Bioregional Assessment (Coal and coal seam gas resource assessment).

Tight gas

The Strzelecki Group experienced much higher temperatures in the past (during the middle Cretaceous, 100 to 90 Ma). The Strzelecki Group may be considered the source, reservoir and seal for tight gas. Fluvial source rocks are carbon rich with numerous flecks of coal and plant debris clearly visible in core and outcrop samples, likely being gas-prone kerogen sources, and the required thicknesses of around 500 m of sediments occur throughout the basin except at its margins. Additionally, the modern thermal regime includes regions of the Strzelecki Group that appear to be in the gas generating window (150 °C). However, the previous higher temperatures may have already stimulated gas production in the past (Harrison et al., 2012). Harrison et al. (2012) also commented that there may be regions of the Strzelecki Group where current temperatures are higher than paleo-temperatures and might be in the gas generating window.

Bradshaw et al. (2012) reported that the Gippsland Basin contains approximately 1853 PJ of tight gas for the Wombat, Gangell and Triforn/North Seaspray reported discoveries. These discoveries are onshore, within the Strzelecki Group in the Seaspray Depression.

Shale gas

Bradshaw et al. (2012) did not identify the Gippsland Basin as being prospective for shale gas formations. There are no shales of deep marine origin with algal kerogen in the Gippsland Basin.

1.1.3.4.3 Other reservoir resources

Water

The sedimentary units of the Gippsland Basin also host significant groundwater resources that are utilised for a variety of industries. Groundwater will be discussed further in Section 1.1.4.

Geothermal

Harrison et al. (2012) included information on geothermal prospectivity in the Gippsland Basin, particularly onshore. Harrison et al. (2012) noted that Cenozoic sediments in the onshore Gippsland Basin have lower thermal conductivity on average than comparable rocks around the world and that this leads to higher temperatures in the subsurface that may enable low temperature geothermal energy use (e.g. supplementary water heating at coal fired power stations potentially increasing coal use efficiency). Groundwater temperatures ranging from 30° C to 70° C have been recorded from depths between 500 and 1000 m in the Gippsland Basin. The hottest groundwater is in the Latrobe Valley and Lake Wellington depressions. Geothermal gradients in these areas range from less than 2° C/100m to over 10° C/100m (Leonard and King, 1992).

CO_2 sequestration

The Gippsland Basin has had a high level, preliminary assessment undertaken for geological storage reservoirs for CO_2 sequestration. Goldie Divko et al. (2009) provided a summary of the geological carbon storage potential of the onshore Gippsland Basin identifying preliminary targets for storage as well as preliminary estimates of potential storage volumes, including within the Strzelecki Group and Latrobe Group. Goldie Divko et al. (2009) emphasised that significantly more work investigating fault permeability and seal integrity is required to more adequately assess CO_2 storage potential. Offshore, the Gippsland Basin has been identified as a highly prospective area for CO_2 sequestration (Geoscience Australia, 2014).

The principal reservoir target is the Latrobe Group and the potential storage areas are generally current and future depleted oil and gas fields, located in the northern and central parts of the offshore basin. This poses a reservoir use optimisation problem with future CO_2 storage potential depending on oil and gas resource extraction scheduling. Areas of near-shore and southern parts of the basin have recently been made available for exploration for CO_2 sequestration via the Offshore Greenhouse Gas Storage Acreage Release (Geoscience Australia, 2014).

1.1.3.5 Potential basin connectivities

1.1.3.5.1 Underlying and adjacent basins and fractured bedrock aquifers

The Gippsland Basin is completely underlain by older Paleozoic rocks which form the geological basement to the basin strata. Thus, the Gippsland Basin is not directly connected or adjacent to any other sedimentary basins. The uppermost Quaternary sediments are considered part of the Gippsland Basin sequence.There are fractured rock aquifer systems within the Paleozoic basement underlying Gippsland Basin (Sinclair Knight Merz, 2009). Sinclair Knight Merz (2009) reported there are a significant number of bores drilled to basement in the Latrobe Valley and Lake Wellington depressions, and fewer in the Lakes Entrance Platform and Seaspray Depression.

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1.1.4 Hydrogeology and groundwater quality

Summary

The main aquifer systems of the Gippsland Basin bioregion are those of the Gippsland Basin, with less extensive aquifer systems in the Moe Swamp and Tarwin sub-basins. The aquifers of the Moe Swamp and Tarwin sub-basins are disconnected from each other and from the Gippsland Basin as a result of structural compartmentalisation of these areas.

The groundwater flow systems of the Gippsland Basin bioregion are complex as a result of the dynamic depositional environment of the Gippsland Basin as well as tectonic movements experienced after deposition. The flow systems have been grouped into four flow systems based on the Victorian Aquifer Framework groupings of the geological units of the basin, including the bedrock aquifer system made up of fractured Paleozoic and Cretaceous rocks, the lower aquifer system of the Eocene to Oligocene age, the middle aquifer system of the Oligocene to Miocene age and the upper aquifer system of the Quaternary age. The groundwater flow systems of the Tarwin and Moe Swamp sub-basins are described separately as they form separate groundwater catchments.

Groundwater quality varies with depth as well as across the basin within and between the different aquifers. Many of the aquifers are high yielding and contain high quality groundwater. Groundwater is utilised for irrigation, urban water supply, stock and domestic use, industrial uses and power station cooling. Groundwater is also extracted as part of the oil and gas recovery process in the offshore part of the Gippsland Basin and as part of dewatering programmes for coal mine stabilisation in the Latrobe Valley.

Groundwater is also an important water source for many ecosystems across the Gippsland Basin bioregion, and shallow aquifers tend to receive both water from and discharge water to rivers in the bioregion.

There has been extensive investigation of the hydrogeology of the Gippsland Basin. This overview synthesises the existing knowledge of the hydrogeology of the Gippsland Basin and the Moe and Tarwin sub-basins.

1.1.4.1 Groundwater systems

The main aquifer systems of the Gippsland Basin bioregion are those of the Gippsland Basin, with less extensive aquifer systems in the Moe Swamp and Tarwin sub-basins. The aquifers of the Moe Swamp and Tarwin sub-basins are disconnected from each other and from the Gippsland Basin as a result of structural compartmentalisation of these areas. As a result, they are separate groundwater catchments.

The groundwater flow systems in the Gippsland Basin are complex as a result of variability in litho-stratigraphy and hydraulic properties. Some aquifers extend over large areas, and partly into the offshore parts of the basin, through complex geological structures. Other aquifers are only of local extent (Schaeffer, 2008). The lithologies of the regional aquifer systems are relatively consistent in a north-south direction across the onshore portion of the basin. However, from west to east, the lithologies vary from being predominantly coal rich, to a sandy sequence and then predominantly limestone and marl (Schaeffer, 2008). The flow systems of the Moe Swamp and Tarwin sub-basins are less complex than the Gippsland Basin, as the sedimentary depositional environments have been terrestrial only in these sub-basins.

Extensive aquifer and aquitard mapping of the Gippsland Basin has been undertaken (GHD, 2012; Sinclair Knight Merz, 2009). The Victorian Aquifer Framework (VAF) groups hydrogeological units according to their age. This is based on a tiered approach that identifies geological units, hydrogeological units and finally aquifers and aquitards. The VAF definitions are adopted for the Gippsland Basin Bioregional Assessment. The aquifers and aquitards are grouped further for the purposes of this study (Figure 22 and Table 15):

- **bedrock aquifer system** (Cretaceous, and Ordovician to Carboniferous): Strzelecki Group and Paleozoic basement sediments and intrusives
- **lower aquifer system** (Eocene to Oligocene): Latrobe Group sediments and volcanics
- **middle aquifer system** (Oligocene to Miocene): Latrobe Valley Group and Seaspray Group sediments
- **upper aquifer system** (Pleistocene to Quaternary): Sale Group sediments.

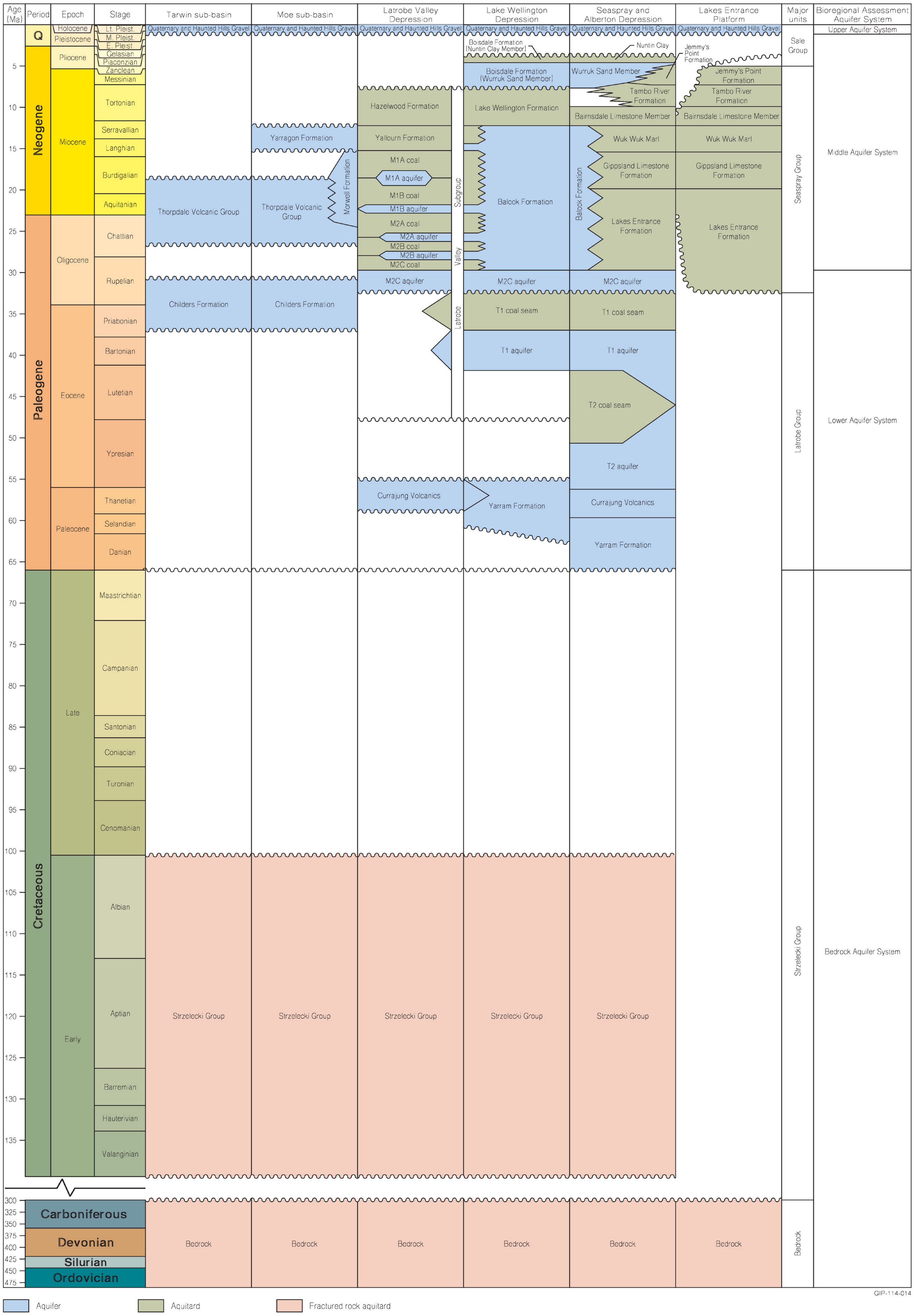


Figure 22 Hydrostratigraphy of the Gippsland Basin, and Moe Swamp and Tarwin sub-basins

Source: Schaeffer (2008)), drawing also on the work of Pratt (1985), Brumley and Holdgate (1983) and Nicol (2010)

Note: This figure has been optimised for printing on A3 paper (297 mm x 420 mm)

Table 15 Guide to hydrostratigraphy indicating relationships between the Victorian Aquifer Framework naming conventions and the hydrogeological units used in the Bioregional Assessment

Name of aquifer system for Bioregional Assessment	Victorian Aquifer Framework aquifer and aquitard name	Hydrogeological unit(s)
Upper aquifer system (Pleistocene to Holocene): Sale Group sediments	Quaternary and upper Tertiary aquifer (AQ102) Quaternary and upper Tertiary aquitard (AQD103)	Various Quaternary deposits, Haunted Hills GravelGravel, Eagle Point Sand Member Boisdale Formation (Nuntin Clay), Sale Group and Jemmys Point Formation
Middle aquifer system (Oligocene to Miocene): Latrobe Valley Group and Seaspray Group sediments	Upper Tertiary (fluvial) AQ105) Upper Tertiary aquitard (AQD106) Upper middle Tertiary aquifer (AQ107) Upper middle Tertiary aquitard (AQ108)	Boisdale Formation (Wurruk Sand) Hazelwood Formation, Yallourn Formation Balook Formation, Morwell Formation (Morwell 1 coal, Morwell 1 interseam, Morwell 2 coal, M1 A coal, M1A interseam, M1B coal, M1B interseam, M2A coal, M2A interseam, M2B coal, M2B interseam, M2C coal(s)), Yarragon Formation, Alberton Coal Measures, Cobia Subgroup, Gurnard Formation and Turrum Formation Seaspray Group, Wuk Wuk Marl, Gippsland Limestone, Lakes Entrance Formation, Tambo River Formation, Giffard Sandstone Member
Lower aquifer system (Eocene to Oligocene): Latrobe Group, basal coal units of the Morwell Formation sediments and volcanics	Lower middle Tertiary aquifer (AQ109) Lower Tertiary aquifer (basalt) (AQ112) Lower Tertiary aquifer (AQ111)	M2C aquifer or Seaspray Sand Thorpdale Volcanics, Carrajung Volcanics M2 Aquifer, Latrobe Group, Yarram Formation, Honeysuckle Hill Gravels, Childers Formation, Burrong Formation, Traralgon Formation or Seams
Bedrock aquifer system (Cretaceous and Ordovician to Carboniferous): Strzelecki Group and Paleozoic basement sediments and intrusives	Basement	Strzelecki Group, Paleozoic bedrock

1.1.4.1.1 Bedrock aquifer system (Cretaceous and Ordovician to Carboniferous): Strzelecki Group and Paleozoic basement sediments and intrusives

The Cretaceous age Strzelecki Group and the Paleozoic rocks are often referred to as groundwater basement due to their low matrix permeability. Most of the outcropping bedrock comprises Silurian-Devonian metasediments, Devonian granites and Cretaceous sediments. While not transmitting large quantities of groundwater in the Gippsland Basin, the bedrock aquifers are known to maintain baseflow in many of the streams and rivers in the Gippsland Basin bioregion (Nicol, 2010). Groundwater flow through the bedrock aquifers is generally via fractures, however some matric flow may occur where significant weathering of the rocks has occurred. Fracture porosity generally decreases with depth such that groundwater resources are generally limited to the upper 150 m of the units (Walker and Mollica, 1990). Bore yields are typically less than 1 L/second but are highly variable over short distances. Yields are typically lower in the granite bedrock (less than 0.5 L/second).

Walker and Mollica (1990) stated that the major fault movements within the Strzelecki Group have taken place along near vertical faults and higher transmissivities may occur within these zones. Walker and Mollica (1990) also stated that there is likely to be more fracturing within the Paleozoic rocks, relative to the Strzelecki Group, due to their significantly older age and therefore greater exposure to fault movements.

The groundwater system of the Strzelecki Group outcrops mainly in the Strzelecki Ranges. A small area of outcrop is also found to the north of Yallourn as well as to the south of Leongatha where it also subcrops in places beneath a thin veneer of Cenozoic sediments (Walker and Mollica, 1990).

1.1.4.1.2 Lower aquifer system (Eocene to Oligocene): Latrobe Group, basal coal units of the Morwell Formation sediments and volcanics

The lower aquifer system extends over most of the onshore Gippsland Basin as well as extending offshore. Included in this group are the Latrobe Group sediments and the Thorpdale and Currajung volcanics. These are non-marine sediments deposited in alluvial-fluvial, fluvial-deltaic and paralic environments and include thick sandstones, shales, mudstone, coal and volcanics. The Latrobe Group sediments are generally not visible in outcrop, while the Thorpdale and Currajung volcanics outcrop extensively.

Onshore, the Latrobe Group has been subdivided into two aquitards and two aquifers: the T1 coal, overlying and confining the T1 aquifer; and the T2 coal, overlying and confining the T2 aquifer (Schaeffer, 2008). These aquifers are generally high yielding (up to 100 L/second) and of good quality, forming the most reliable groundwater source in the onshore part of the Gippsland Basin (Hatton et al., 2004). The T1 aquifer is regionally extensive, present in the Latrobe Valley Depression from east of the Morwell Monocline, and throughout most of the Gippsland Basin. The T2 aquifer also occurs across most of the Gippsland Basin, however it is less prominent than the T1 aquifer in the Latrobe Valley Depression, and more prominent further east and south of the Rosedale Fault (Schaeffer, 2008). The T1 and T2 aquifers are generally composed of sand, gravel, clay, minor coal and volcanics (Schaeffer, 2008). The aquitards are not explicitly defined as specific units in the VAF, however they can be thought of as lower permeability units within the lower Tertiary aquifer of the VAF and are important for local-to-regional scale groundwater flow. The T2 aquitard is not regionally extensive. The T1 aquitard is regionally extensive and therefore the principal confining unit within the lower Tertiary aquifer system (Nicol, 2010). Isopachs of the T1 and T2 coal seams were mapped by Holdgate et al. (2000). The composition of the T1 and T2 aquitards is mainly coal with minor gravel, sand, silt and clay (Schaeffer, 2008).

The M2C aquifer (the basal unit of the Morwell Formation) and its facies equivalent, the Seaspray Sand can also be grouped into the lower aquifer system. The M2C aquifer (and its lateral equivalents) extend from the Moe Swamp sub-basin in the west (where it is called the Childers Formation), to the Bairnsdale or Lakes Entrance area (where it is called the Seaspray Sand), effectively passing beneath, but in direct hydraulic contact with, the Balook Formation. The M2 equivalents also extend offshore. Onshore, it is present in the Latrobe Valley, the Lake Wellington Depression and the Seaspray Depression. The Childers Formation (M2 equivalent) also occurs in the Tarwin sub-basin. The M2C aquifer is composed of sand, clay and gravel (Schaeffer, 2008).

Equivalents of the M2C, T1 and T2 aquifers extend into the offshore Gippsland Basin (Schaeffer, 2008).

Away from the Latrobe Valley Depression and the Western Seaspray Depression, the lower aquifer system is confined by the Lakes Entrance Formation. As such, vertical groundwater movement between the lower aquifer system and the overlying middle aquifer system is limited. Walker and Mollica (1990) stated that, although this is the case, under pumping stress leakage from overlying and underlying aquifers is significant. In addition, there are exceptions to the distribution of low permeability confining units above the lower aquifer system. These include areas where the Balook Formation exists and where the Colquhoun Gravels are found locally in the area east of Bairnsdale.

The Latrobe Group sediments are up to 100 m thick in the Latrobe Valley and thicken in an offshore direction to more than 3000 m. Their maximum onshore thickness is 1000 m (Hatton et al., 2004), in the Seaspray Depression. The depth to the aquifer system also generally increases towards the coast away from the basin margins, except in the region of the Baragwanath Anticline and Rosedale Fault where the sediments have been uplifted so that they subcrop at a relatively shallow depth (Nicol, 2010).

Offshore, the Latrobe Group aquifers are the reservoir rocks for the giant oil and gas fields of the Gippsland Basin. Coal mine depressurisation in the Latrobe Valley Depression and the offshore oil and gas developments are the major users of the water resources of the lower aquifer system. The Thorpdale and Currajung volcanics are also important aquifers and are considered part of the lower aquifer system. Hydraulic conductivities in the Thorpdale Volcanics range from less than 1 to 18 m/day. They are generally high-yielding aquifers with permeable structures, such as joints, fissures, fractures and interfaces between basalt flows (Hofmann, 2011).

1.1.4.1.3 Middle aquifer system (Oligocene to Miocene): Latrobe Valley Group and Seaspray Group sediments

The middle aquifer system transitions between three regions in the onshore portion of the Gippsland Basin with relatively distinct hydrogeological properties. In the east (near Orbost) and the south, the system is dominated by marine rocks, limestones and marls of the Seaspray Group.

Heading west and north towards the Latrobe Valley Depression, the sandstone of the Balook Formation (deposited as barrier sands with interbedded clays) dominates the system. Heading further west and north into the Latrobe Valley Depression, alluvial and fluvial sediments, sandstones, coal, siltstones and shales of the Latrobe Valley Group dominate. Note that the Latrobe Valley Group sediments are younger in age than the Latrobe Group sediments and are geologically and hydrogeologically distinct (see Figure 20 of Section 1.1.3.2).

The marine rocks in the east: the Lakes Entrance Limestone, Gippsland Limestone and Wuk Wuk Marl, are classified as relatively poor aquifers or aquitards. The Lakes Entrance Formation is generally described as a leaky aquitard onshore. It is described as a regional seal in the oil and gas and carbon dioxide sequestration literature, e.g. Goldie Divko et al. (2009), for the offhsore part of the basin. The Lakes Entrance Formation is thought to thin in the northern region of the Gippsland Lakes, potentially accommodating upward flow of groundwater from the lower aquifer to the middle aquifer system (Varma and Michael, 2012). The Gippsland Limestone is a low hydraulic conductivity confined aquifer, although sandier sheets and horizons may have higher conductivity, yielding up to 10 L/second, but typically less than 2 L/second (Minchin, 2010). The Wuk Wuk Marl is a poor (low yielding) aquifer. The marine sediments are utilised for stock and domestic water supply in a few areas on the Lakes Entrance Platform and to a limited extent around the Baragwanath Anticline. The VAF groups these formations together as an aquitard – the 'upper middle Tertiary aquitard'.

The Balook Formation extends north-north-east for 150 km across the Seaspray and Lake Wellington depressions, except in the area of the Baragwanath Anticline (Nicol, 2010). It has limited lateral extent (about 30 km) but is important in providing vertical connection between the lower aquifer system and the middle and upper aquifer systems (Hofmann and Cartwright, 2013; Nicol, 2010). It also provides lateral connection between the Morwell Formation in the west and the Lakes Entrance Formation in the east, and the Yallourn Formation in the west and the Gippsland Limestone in the east (Hofmann and Cartwright, 2013). Balook Formation thickness is mapped up to 500 m, but due to limited lateral extent this unit is not well developed as a resource.

Within the Latrobe Valley Depression, the middle aquifer system is divided into a series of aquifers and aquitards (M1A coal, M1A aquifer, M1B coal, M1B aquifer, M2A coal, M2A aquifer, M2B coal, M2B aquifer, M2C coal). The coal seams are defined as aquitards and the interseams are defined as aquifers (Schaeffer, 2008). The M1B aquifer is regionally extensive across the Latrobe Valley Depression and is confined by the M1B coal.

Also grouped in the middle aquifer system are middle-to-late Miocene age sediments including the Boisdale (Wurruk Sand Member) and Jemmys Point formations, and in the Latrobe Valley Depression, the Hazelwood and Yallourn formations.

The Yallourn, Hazelwood and Jemmys Point formations are considered to be an aquitard within the VAF (GHD, 2012). The Yallourn Formation is a major coal-bearing unit of the Latrobe Valley Depression. The Hazelwood Formation is a predominantly clay unit with minor coals, also limited to the Latrobe Valley Depression. These units interfinger with the Balook Formation and the Boisdale Formation to the east. The formations overlie the M1A aquifer and coal in the Latrobe Valley Depression. In the Moe Swamp sub-basin, the Yarragon Formation is stratigraphically equivalent to the Yallourn Formation. The base of the Yarragon Formation consists predominantly of sands, behaving as an aquifer, while coals and clays predominate towards the top of the sequence, confining the basal aquifer.

The Boisdale Formation (Wurruk Sand Member) is a fluviatile sand aquifer. It extends across much of the Gippsland Basin: in the Lake Wellington Depression from Paynesville in the east to Briagolong in the north, Rosedale in the north-west; and across the Seaspray and Alberton depressions, from the Lake Wellington area, to near Yarram in the south-west (Nicol, 2010). The Boisdale Formation thins in the east and is absent in the Lakes Entrance area (Nicol, 2010). The Boisdale aquifer (Wurruk Sand Member) is confined to semi-confined by either the Boisdale Formation (Nuntin Clay Member) or by clays within the overlying Haunted Hills Gravel. It is highly permeable, particularly around Sale, where it is used for urban water supply and irrigation (Nicol, 2010).

1.1.4.1.4 Upper aquifer system (Pleistocene to Holocene): Sale Group sediments

The upper aquifer system includes the lower permeability unit of the Boisdale Formation (the Nuntin Clay Member), the Haunted Hills Formation, the Eagle Point Sand Member and various undifferentiated Quaternary deposits. The Boisdale Formation (Nuntin Clay) is defined as an aquitard, partially confining the Boisdale Formation aquifer (Wurruk Sand) in the areas around Sale. The Haunted Hills Gravel, Eagle Point Sand Member and undifferentiated Quaternary deposits are relatively thin units extensive across the plains of the Gippsland Basin. The Haunted Hills Gravel can range in thickness from between 5 and 100 m (Hofmann, 2011). The aquifers of the Haunted Hills Gravel and Quaternary deposits are generally within 30 m of the land surface and are unconfined to semi-confined (Walker and Mollica, 1990).

Quaternary sediments form surficial aquifers over low-lying areas of the Gippsland Basin. The sediments are of alluvial and coastal origin, with the main aquifers developed in beach and dune sands, and sand and gravel formed by the paleodrainage of major rivers in the region. Extensive Quaternary deposits form productive aquifers in the valleys of the Mitchell, Avon, Thomson, Macalister and Latrobe rivers where these rivers, and their paleochannels, have traversed the Gippsland plains (Walker and Mollica, 1990). In the region bounded roughly by Maffra, Heyfield, Rosedale and Sale, the paleochannels of the Thomson, Avon, Macalister and Latrobe rivers have tended to coalesce, forming an area of significant aquifers made up of interfingering zones of coarser grained and finer grained sediments (Walker and Mollica, 1990). The aquifer associated with the Mitchell River is generally limited to a long narrow valley west of Bairnsdale.

The Quaternary sediments extend outside the boundary of the Gippsland Basin. In these areas, the sediments overlie shallow Paleozoic basement to depths of around 50 m. Sand and gravel layers form unconfined aquifers, usually approximately 5 to 15 m thick with variable yields but typically less than 5 L/second (Nicol, 2010). The Haunted Hills Gravel overlies the Yarragon Formation in the Moe Swamp sub-basin and overlies the Thorpdale Volcanics in the Tarwin sub-basin. In the Tarwin sub-basin, the Haunted Hills Gravel and the Thorpdale Volcanics form a single unconfined aquifer (Nicol, 2010).

Quaternary dune and beach sand deposits along the present coastline form aquifers that are utilised for town water supply at Venus Bay, Loch Sport and Sandy Point. In these near-shore aquifers, shallow bores exploit freshwater lenses that wedge out over more saline groundwaters influenced by the sea (Walker and Mollica, 1990).

1.1.4.2 Groundwater quality

In this section, groundwater quality is reported in terms of salinity (mg/L total dissolved solids (TDS)), drawing on readily available information. The Victorian Government (Department of Environment and Primary Industries) has produced groundwater salinity maps for each of the aquifer layers within the VAF (e.g. Sinclair Knight Merz, 2014). These salinity maps reflect all salinity data available through time, rather than a time slice of salinity distribution (Sinclair Knight Merz, 2014). The most recent update of these maps is presented in Section 1.1.4.2.1 for each of the aquifer systems of the Gippsland Basin and the Moe Swamp and Tarwin sub-basins.

There is limited published research about the hydrogeochemistry of the Gippsland Basin for understanding groundwater flow patterns and inter-aquifer mixing. A recent study by Hofmann and Cartwright (2013) is one of the most comprehensive studies investigating the use of hydrogeochemistry for understanding aquifer systems in the Gippsland Basin. This study focused on the groundwater systems of the Latrobe Valley and Lake Wellington depressions. The major findings of the study were: major ion chemistry of groundwater in all aquifers is similar across the basin, with no systematic changes along flow paths; localised preferential flow paths, as well as regional hydraulic gradients, influence the chemistry of the groundwater; and relatively indistinct groundwater chemistry between the different aquifers of the Gippsland Basin within the Latrobe Valley and Lake Wellington depressions indicates that inter-aquifer mixing and leakage may be significant. Hofmann and Cartwright (2013) noted that the extent to which groundwater extraction has influenced the degree of inter-aquifer mixing is not known as there is no historical geochemical data available to undertake such an investigation. Groundwater flow systems will be discussed in further detail in Section 1.1.4.3.

1.1.4.2.1 Spatial variability of groundwater quality

Figure 23 presents maps of groundwater salinity in the Gippsland Basin.

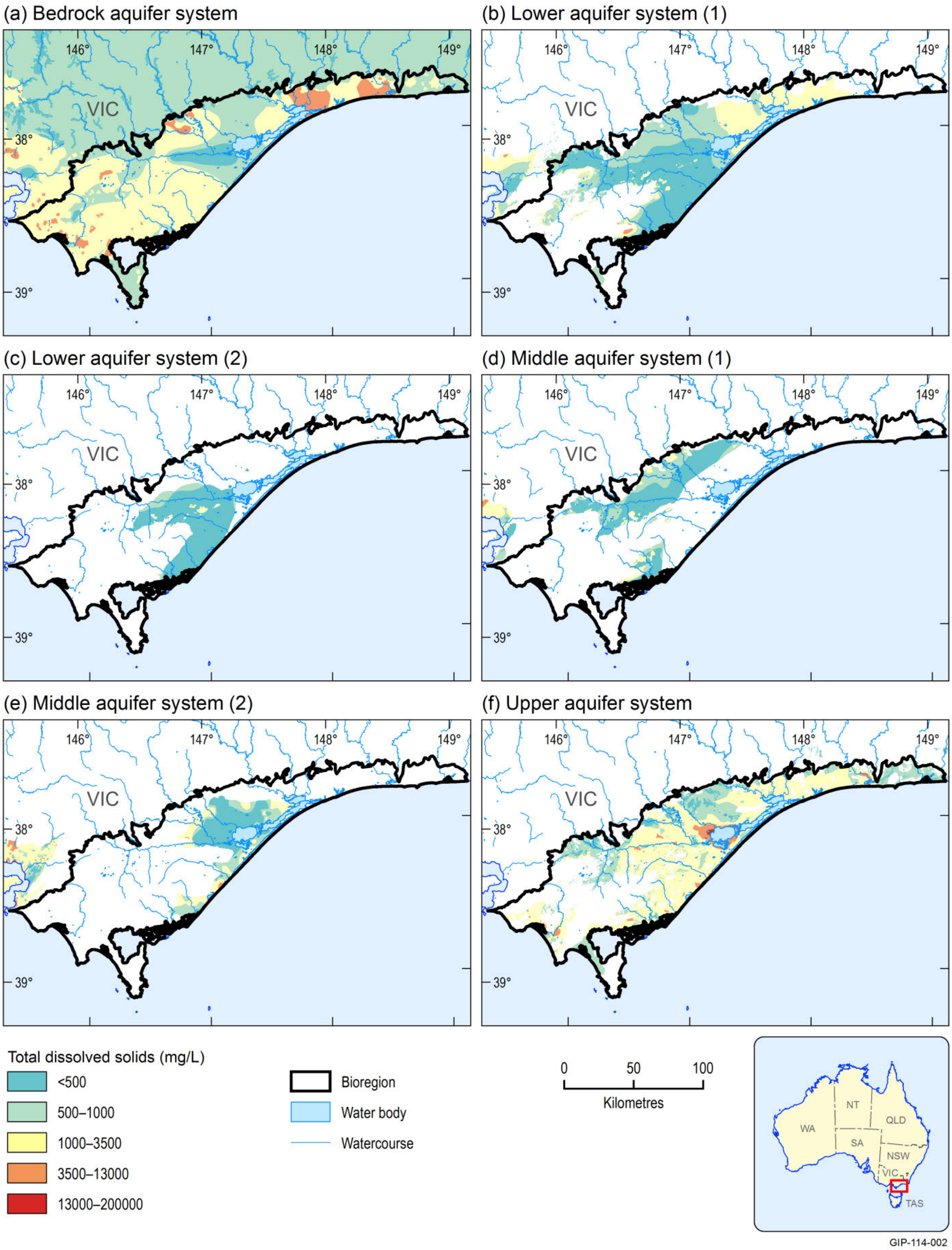


Figure 23 Groundwater salinity (total dissolved solids (mg/L)) in the Gippsland Basin bioregion

Figure (a) is salinity of the Strzelecki Group and Paleozoic fractured rock aquifer; Figure (b) is salinity of the lower Tertiary aquifer and the lower Tertiary aquifer (basalt) grouped together here as Lower aquifer system (1); Figure (c) is the lower middle Tertiary aquifer, referred to here as Lower aquifer system (2); Figure (d) is the upper middle Tertiary aquifer, referred to here as middle aquifer system (1); Figure (e) is the upper Tertiary (fluvial) aquifer, referred to here as Middle aquifer system (2); and Figure (f) is the Quaternary and upper Tertiary aquifer

Data: Victoria Department of Environment and Primary Industries (Dataset 1)
The salinity data presented is from the Victorian Aquifer Framework project and as such, is presented in a manner consistent with the Victorian Aquifer Framework.

Bedrock aquifer system (Cretaceous and Ordovician to Carboniferous): Strzelecki Group and Paleozoic basement sediments and intrusives

The data coverage in the bedrock aquifer is very poor and so there is low confidence in the distribution of groundwater salinity within the bedrock fractured rock aquifer presented in Figure 23 (a). In general, the picture is one of low salinity groundwater (<500 mg/L) in the vicinity of the Baragwanath Anticline and areas of higher salinity groundwater (3500 to 13,000 mg/L TDS) throughout the remainder of the bedrock aquifer, particularly in the region of Heyfield, Metung – Lakes Entrance, Orbost and Marlo. The Paleozoic fractured rock aquifers appear to have lower salinity than the Strzelecki Group fractured rock aquifers.

Lower aquifer system (Eocene to Oligocene): Latrobe Group, basal coal units of the Morwell Formation sediments and volcanics

Groundwater salinity in the lower aquifer system (Figure 23 (b)) is generally below 3500 mg/L TDS. Salinity generally increases towards the east. Groundwater of the lower aquifer system has particularly low salinity in the western part of the Gippsland Basin and in the Moe Swamp sub-basin, with salinity generally less than 1000 mg/L TDS. Patches of elevated salinity are also evident along the edge of the Strzelecki Range and on the crest of the Baragwanath Anticline. The overlying aquifers also have elevated salinity in these areas.

In the Tarwin sub-basin (Figure 23 (c)), groundwater salinity in the Childers Formation/Thorpdale Volcanics Aquifer ranges from 200 to 2000 mg/L TDS, and tends to decrease at greater aquifer depths (Nicol, 2010). In the Moe Swamp sub-basin, groundwater salinity varies from less than 500 to 1000 mg/L TDS.

Middle aquifer system (Oligocene to Miocene): Latrobe Valley Group and Seaspray Group sediments

The uppermost part of the middle aquifer system (Figure 23 (d)), the Boisdale Formation (Wurruk Sand Member) is an important aquifer within the Gippsland Basin due to its high pumping yields and generally low salinity. The groundwater salinity is generally less than 500 mg/L TDS, however higher salinity groundwater (500 to 3500 mg/L TDS) is evident in the region between Rosedale and Maffra in the north; in the eastern part of the aquifer, towards Lakes Entrance; and in the south-west and south along the coast.

Groundwater of the Balook Formation, Morwell Formation, Yarragon Formation and Alberton Coal Measures aquifers is of good quality, generally having salinity of less than 500 to 1000 mg/L TDS. Higher salinities are evident along the bedrock boundaries in the north (up to 3500 mg/L TDS), along the crest of the Baragwanath Anticline (up to 13,000 mg/L TDS) and north and south of the Strzelecki Range (Figure 23 (e)). A similar pattern of elevated salinities in the lower aquifer is also evident in these areas.

Upper aquifer system (Pleistocene to Holocene): Sale Group sediments and recent Quaternary

Low salinity groundwater (<1000 mg/L) is found in the aquifers of the recent Quaternary and Sale Group sediments in the Lake Wellington catchment and Mitchell River valley as well as around the regions of Moe and Orbost, the South Gippsland Coast and in the upper valleys of the Macalister, Mitchell, Tambo and Snowy rivers (Southern Rural Water, 2012). Groundwater within the surficial aquifers across the remainder of the Gippsland Basin bioregion is generally of poorer quality (>1000 mg/L). High salinity groundwater (mainly within the class 3500 to 13,000 mg/L TDS) exists in the vicinity of Lake Wellington and within the Macalister Irrigation District, as well as some areas along the coast.

Hofmann and Cartwright (2013) interpreted hydrogeochemical data to indicate that higher salinity groundwater in younger units in the Gippsland Basin is likely the result of significant evapo-concentration of shallow groundwater.

About 110 km^2 of Gippsland's farmland is affected by irrigation-induced salinity and about 130 km^2 is affected by dryland salinity (DSE, 2011). Salinisation in Gippsland has been caused by land clearing and inefficient irrigation which leads to an elevated watertable. Salinity has been an issue for the Macalister Irrigation District as well as low-lying areas with naturally high watertables near the coast and the Gippsland Lakes. Within the Macalister Irrigation District, salinity is actively managed by pumping from public and private groundwater bores and improving surface drainage to lower the watertable (DSE, 2011). A network of 260 observation bores across the Lake Wellington catchment is managed by the West Gippsland Catchment Management Authority. Quarterly groundwater level monitoring of selected bores within this network is undertaken to ensure that salinity interception pumps are managed optimally. A depth to watertable map is produced annually from this data.

Additionally, DSE (2011) reported that there is potential for seawater intrusion in the Clydebank area near Lake Wellington and the Yarram area in South Gippsland. DSE (2011) reported that in these areas, restrictions on groundwater extraction and pumping rates have been implemented to manage seawater intrusion risk.

1.1.4.2.2 Temporal variability of groundwater quality

Aside from shallow groundwater salinity in the irrigation districts of the Gippsland Basin, there are no readily available studies investigating the temporal variability of groundwater quality or temporal trends in groundwater quality in the Gippsland Basin. The groundwater systems of the Gippsland Basin are not in steady state and there have been significant changes to land use and surface and groundwater hydrology in the past four decades. It is therefore likely that there have been changes to the distribution of groundwater quality over time, however, time series groundwater quality monitoring data does not appear to be available to investigate the distribution and magnitude of these changes across the Gippsland Basin. There are approximately 300 bores in the Gippsland Basin bioregion with greater than 15 salinity measurements recorded in the Victorian Groundwater Management System (GMS). These bores are principally located within the macalister irrigation district and of the 300 bores, 294 are less than 50 m deep. The majority of time-series salinity data was collected in the decades 1980-1990, 1990-2000 and 2000-2010.

1.1.4.3 Groundwater flow

The groundwater flow systems of the Gippsland Basin are generally not in a steady state (Nicol, 2010; Underschults et al., 2003; Walker and Mollica, 1990). Groundwater extraction for oil and gas production, coal mining, irrigation and water supply, as well as land use change including land clearing, establishment of irrigation agriculture and afforestation for forest production have significantly altered the recharge and discharge characteristics of the groundwater flow systems of the Gippsland Basin over the last four decades.

The flow systems of the Tarwin sub-basin and the Moe Swamp sub-basin are distinct from each other and those of the Gippsland Basin as a result of structural elements that impede hydraulic connection. This is discussed further in Section 1.1.4.3.2, Section 1.1.4.3.3 and Section 1.1.4.3.4.

1.1.4.3.1 Gippsland Basin

Within the Latrobe Valley and Lake Wellington depressions, vertical head gradients are downward in the west, implying potential for downward flow; and upwards in the east, implying potential for groundwater flow from deeper to shallower units. The upward head gradients are locally large – especially in the area around the Gippsland Lakes where some groundwater is artesian (Hofmann and Cartwright, 2013). Groundwater modelling studies within the Gippsland Basin have suggested that up to one-third of groundwater extracted from the coal-bearing aquifers (the lower aquifer system and the middle aquifer system) within the Latrobe Valley Depression originates from storage in adjacent aquitards, indicating that inter-aquifer leakage may be a significant source of recharge to these aquifers (Schaeffer, 2008). Hofmann and Cartwright (2013) also found evidence of leakage and inter-aquifer connectivity across the Gippsland Basin in their study of the hydrogeochemistry of the Gippsland Basin. Hydrographs for the various aquifer systems show significant contrasts in trends between the deeper confined aquifers of the lower aquifer system and those of the shallower aquifers.

Figure 24, Figure 25 and Figure 26 present modelled groundwater level surfaces for the Gippsland Basin bioregion. The surfaces are based on preliminary modelling and may be subject to change as modelling progresses for the bioregional assessment. They are presented here to indicate the general direction of groundwater flow in these aquifer systems as well as, in general, the changes in groundwater level that have occurred over the last three decades. The trends visible in these maps are discussed further in the section below with the aid of hydrographs.

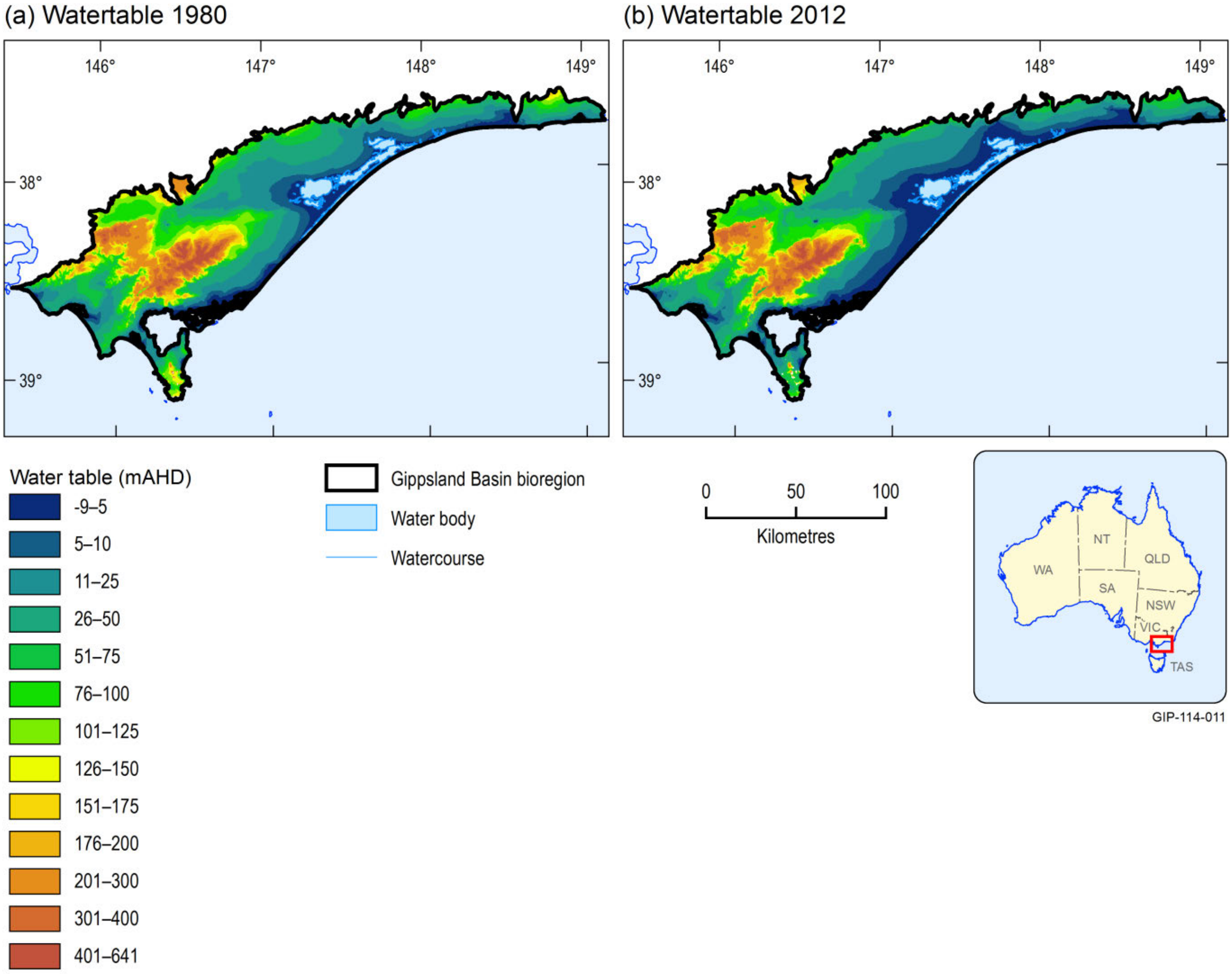


Figure 24 Regional watertable, Gippsland Basin bioregion, (a) 1980 and (b) 2012. Note that this surface is based on preliminary modelling and will be subject to change as modelling progresses for the purpose of the bioregional assessment

Data: Victorian Government (Dataset 2)

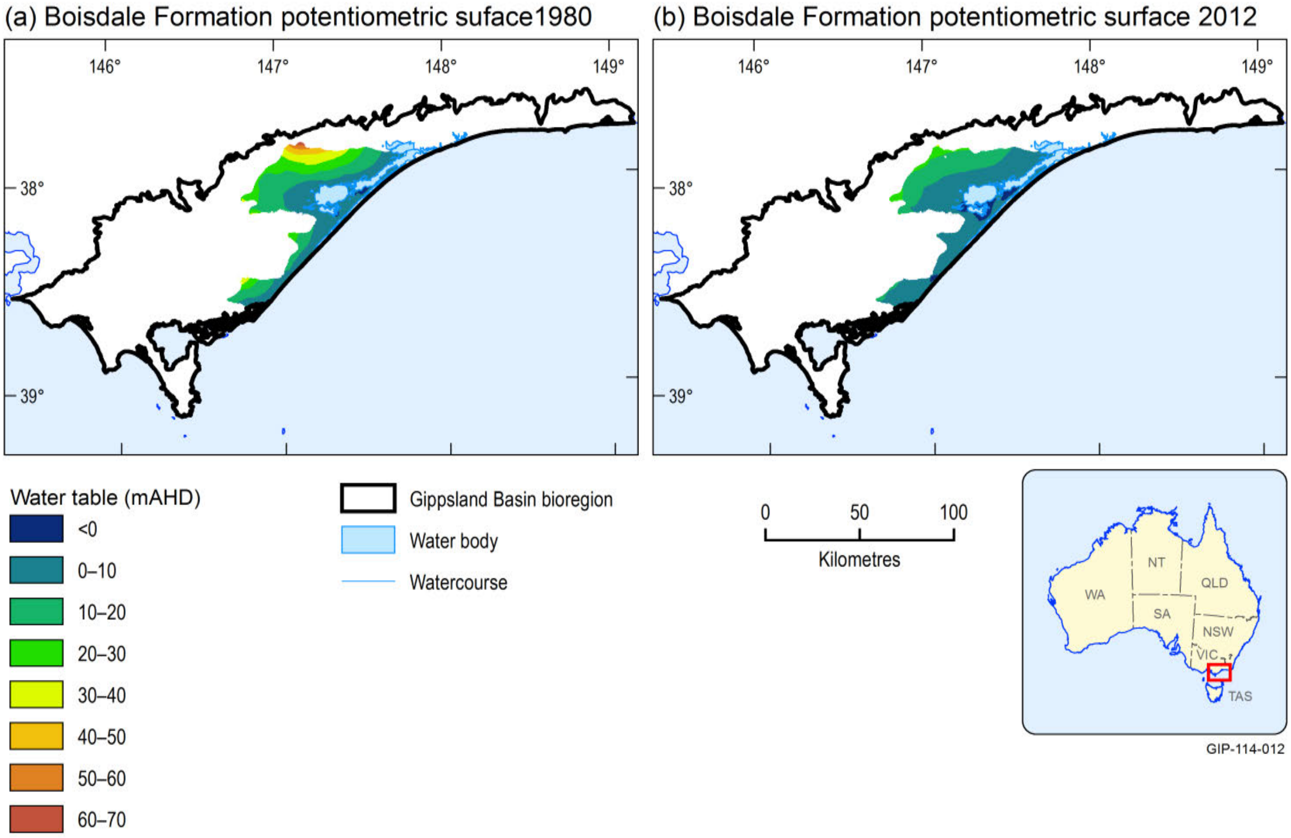


Figure 25 Potentiometric surface, Boisdale Formation (an aquifer of the Middle Aquifer System), (a) 1980 and (b) 2012. Note that this surface is based on preliminary modelling and will be subject to change as modelling progresses for the purpose of the bioregional assessment

Data: Victorian Government (Dataset 2)

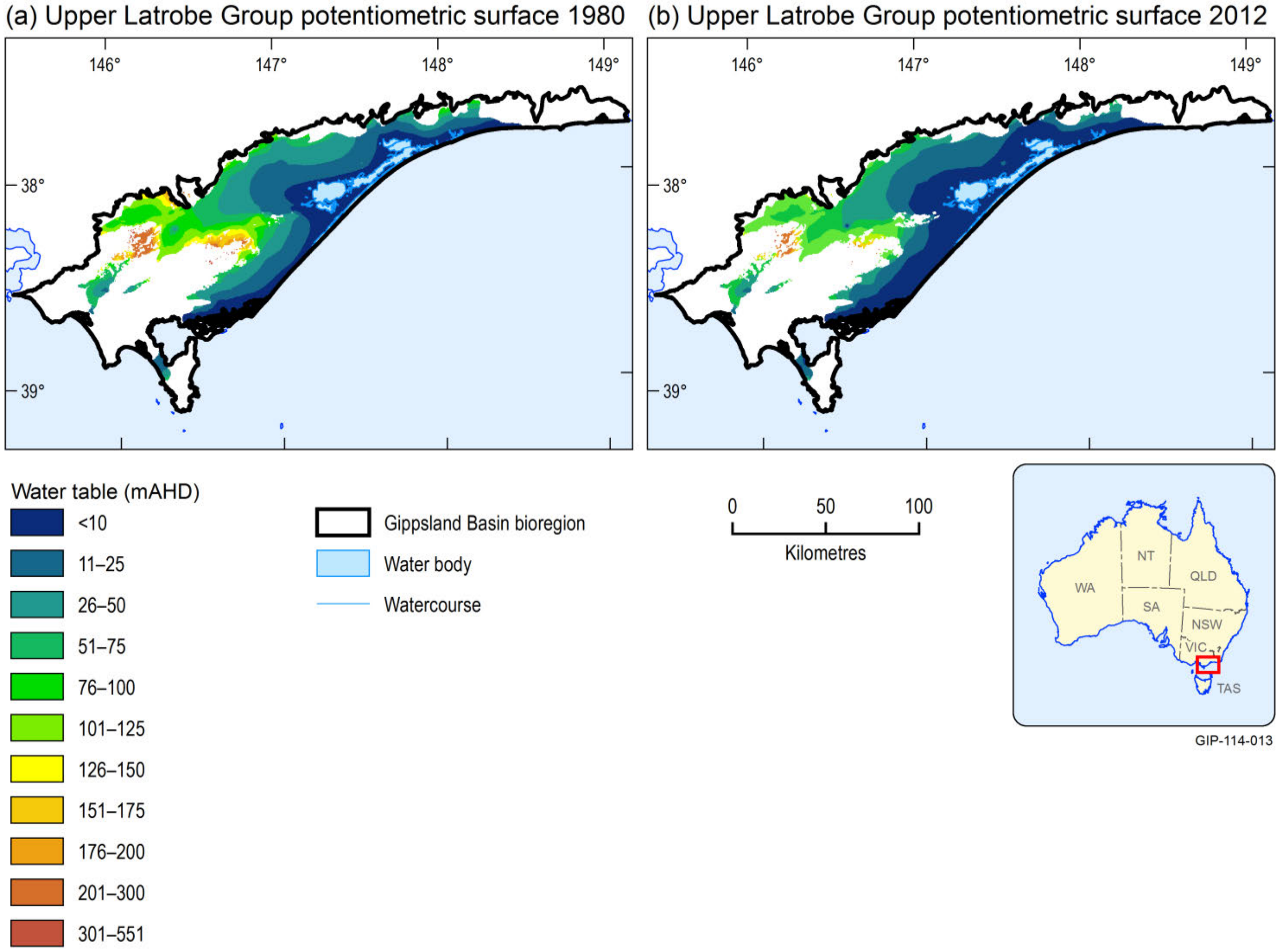


Figure 26 Potentiometric surface, upper Latrobe Group (aquifers of the Lower Aquifer System), (a) 1980 and (b) 2012. Note that this surface is based on preliminary modelling and will be subject to change as modelling progresses for the purpose of the bioregional assessment

Data: Victorian Government (Dataset 2)

Bedrock aquifer system (Cretaceous and Ordovician to Carboniferous): Strzelecki Group and Paleozoic basement sediments and intrusives

The Cretaceous age Strzelecki Group and the Paleozoic rocks are often referred to as groundwater basement due to their low matrix permeability. Groundwater flow does occur in local to intermediate flow systems, dominated by fracture flow. Some localised matrix flow may also occur in the sandier facies and coal seams of the Strzelecki Groups rocks (e.g. Harrison et al. (2012) reported thermal anomalies within the Strzelecki Group that are attributed to groundwater flow in major coal seams within the Strzelecki Group). Groundwater flow in fracture networks is thought to be limited to the upper 50 to 100 m of bedrock and the aquifer system is considered to undergo relatively minor regional throughflow (Nicol, 2010). Groundwater is likely to be recharged locally, transmitted rapidly through fracture networks and ultimately contributes to stream discharge (Nicol, 2010). Previous work has not included detailed study of the hydraulic properties and groundwater flow dynamics of the bedrock aquifer system within the Gippsland Basin bioregion. Should the Strzelecki Formation be found prospective for unconventional gas resources, it is likely that further characterisation of the aquifers and flow systems of the Strzelecki Group will be required to inform both baseline characteristics as well as predictions of the possible changes that may be caused by unconventional gas development. Figure 27 shows a typical hydrograph (bore 144469) for the fractured rock aquifer system. It shows that groundwater levels increase and decline seasonally but generally fluctuate around a central value indicating local flow systems are dominant and that depletion via drainage of fractures either by pumping or to surface water systems is seasonally replenished by rainfall recharge. This is also evident in the increasing trend post 2010 reflecting a return towards average rainfall conditions following the millennium drought.

Lower aquifer system (Eocene to Oligocene): Latrobe Group, basal coal units of the Morwell Formation sediments and volcanics

Recharge to the Latrobe Group aquifer system occurs from rainfall infiltration and stream leakage in areas of outcrop and shallow subcrop. The aquifer system outcrops and subcrops around the basin margins in the west and the north to as far east as about Boisdale, and subcrops beneath Quaternary sediments on the crest of the Baragwanath Anticline and on local structural highs such as the Loy Yang Dome and Hedley Dome (Walker and Mollica, 1990).

Groundwater flow is generally from the recharge areas in the west, towards the offshore to the east and south-east. Natural groundwater discharge is thought to occur offshore where the Latrobe Group sediments are exposed on the continental shelf (Walker and Mollica, 1990). Flow directions are complicated by features such as the Baragwanath Anticline, Rosedale Fault and the associated Rosedale Monocline, which direct flow from the west in an easterly direction until the anticline plunges to sufficient depth to allow flow towards the offshore basin (Nicol, 2010). Groundwater discharge from the Latrobe Group aquifer in the onshore part of the basin occurs at the Dutson Springs on the Baragwanath anticline and around the Hedley Dome near Gelliondale (Thompson and Walker, 1982).

Groundwater flow has been considerably altered since the 1960s as a result of dewatering operations at the Morwell and Loy Yang open-cut mines. Groundwater now flows radially towards the open-cut mine. Groundwater extraction from the Latrobe Group aquifer for the production of oil and gas exceeds estimated annual recharge, causing a 1 to 1.5 m/year decline in groundwater level in the Latrobe Group aquifer within the Latrobe Valley, Lake Wellington Depression and Seaspray Depression since the 1960s to 1970s (Nicol, 2010; Underschultz et al., 2006; Walker and Mollica, 1990). The Traralgon Formation typically shows the greatest and most consistent rates of groundwater level decline in the Gippsland Basin (Nicol, 2010). Groundwater levels in the Latrobe Group aquifer have fallen by approximately 20 m in bores around the coal pits between 1980 and 2010. The cone of depression was located around Morwell in the 1990s and spread to the west towards Traralgon, where head values dropped by 68 m between 1990 and 2008. The groundwater divide around the Balook Block and Baragwanath Anticline shifted to the west as a consequence of the decreasing water levels in the area around the coal mines (Hofmann and Cartwright, 2013).

Thompson and Walker (1982) placed the freshwater-seawater interface within the Latrobe Group aquifer in the Seaspray Depression at about 30 km offshore. A more recent assessment of the location of the freshwater interface is not available.

Figure 28 shows two representative hydrographs for the lower aquifer system within the Gippsland Basin. Bore 67441 is representative of the region of the aquifer north and east of the Baragwanath Anticline, where the aquifer is covered by a thick sequence of sediments of the overlying stratigraphic sequence. The trend evident in the hydrograph is dominated by drawdown from offshore oil and gas production and onshore coal mine floor dewatering. It shows a strongly confined response reflecting significant drawdown and limited recharge. Bore 110724 is located to the south of the Baragwanath Anticline, where the Latrobe Group is closer to the surface, in many areas subcropping the Haunted Hills Gravel, and where it is used intensively for onshore water supply. The hydrograph for bore 110724 shows the effects of offshore oil and gas extraction. In the general decline trend, however, overprinting the drawdown associated with those abstractions are the seasonal abstractions from onshore water supply bores which suggest elastic storage depletion and recovery corresponding to irrigation water demand seasonality. The trend decline may also result in part from these water demands.

Middle aquifer system (Oligocene to Miocene): Latrobe Valley Group and Seaspray Group sediments

Recharge to the marine sediments of the Seaspray Group occurs via rainfall infiltration where these rocks outcrop or are in shallow subcrop. Minor recharge may also occur laterally from groundwater flow from the Balook Formation and the Latrobe Valley Group aquifers (Walker and Mollica, 1990). Groundwater flow within the marine rocks is towards the offshore part of the Gippsland Basin, however, the marine sediments are poor aquifers and aquitards and in the main, act to deflect groundwater upwards as it flows laterally from the non-marine stratigraphically equivalent sediments.

The marginal marine Balook Formation and the non-marine Latrobe Valley Group and Boisdale Formation are all hydraulically connected. Recharge to the system is around the margins of the Gippsland Basin from rainfall infiltration and river leakage. Vertical recharge via leakage from overlying aquifers is also likely to be an important source of recharge, particularly in areas of the aquifer system with large drawdowns caused by groundwater extraction (e.g. Latrobe Valley Depression) (Walker and Mollica, 1990). Recharge is also thought to occur where the sediments subcrop the Haunted Hills Gravel. In particular, this mechanism may be significant for recharge to the Boisdale Formation where the Boisdale Formation subcrop is traversed by the paleochannels and present-day courses of the Latrobe, Thomson, Macalister and Avon rivers (HydroTechnology, 1994; Walker and Mollica, 1990). In the area north and north-west of Sale, the Wurruk Sand Member of the Boisdale Formation subcrops the Haunted Hills Gravel and recent alluvium, providing a very good pathway for recharge from the surficial aquifers to the Boisdale Formation and is considered a major recharge area (HydroTechnology, 1994).

Groundwater flow in the Latrobe Valley Group sediments in both the Latrobe Valley and Lake Wellington depressions is essentially from west to east. It is thought that the flow passes into the Balook Formation and is largely deflected upwards to the Boisdale Formation by the less permeable, marine units of the Seaspray Group. The Latrobe Valley Group aquifers are generally deeply buried and not intensively targeted for groundwater extraction, however there is some stock and domestic use at the western end of the Seaspray Depression and in the Latrobe Valley. There is also dewatering of the aquifers of the Latrobe Valley Group within the Latrobe Valley

Depression for coal mining and extraction of groundwater from these aquifers for power station cooling. These extractions locally influence flow directions (Nicol, 2010).

Movement of groundwater in the Boisdale Formation is west to east in the Latrobe Valley Depression and elsewhere it is north to south towards the offshore part of the basin. The Boisdale Formation passes laterally into the Jemmys Point Formation in the east (which acts as an aquitard) restricting lateral flow and potentially diverting groundwater upwards (Walker and Mollica, 1990). Hydraulic gradients from the Boisdale Formation to Lake Wellington suggest groundwater discharges from the Boisdale Formation to the lake (Hofmann and Cartwright, 2013; Walker and Mollica, 1990).

The Boisdale Formation is used over a large part of the basin to depths of 50 to 100 m for stock and domestic supplies and, in the area around Sale, for irrigation supplies. It is also used for town water supply at Sale (Walker and Mollica, 1990). Groundwater levels in the Boisdale aquifer system have been in gradual decline as a result of overallocated groundwater across the aquifer (Gippsland Water, 2012). Groundwater levels in the Boisdale aquifer near Sale declined by 5 to 10 m between 1990 and 2008 (Hofmann and Cartwright, 2013). Aquifer depressurisation for coal mining and oil and gas development is generally not considered to have affected the groundwater levels of the Boisdale Formation (Nicol, 2010).

Figure 29 shows five hydrographs within the middle aquifer system: bores 52753, 65762, 67442, 86466 and 92175. These bores are all screened within the Boisdale Formation aquifer.

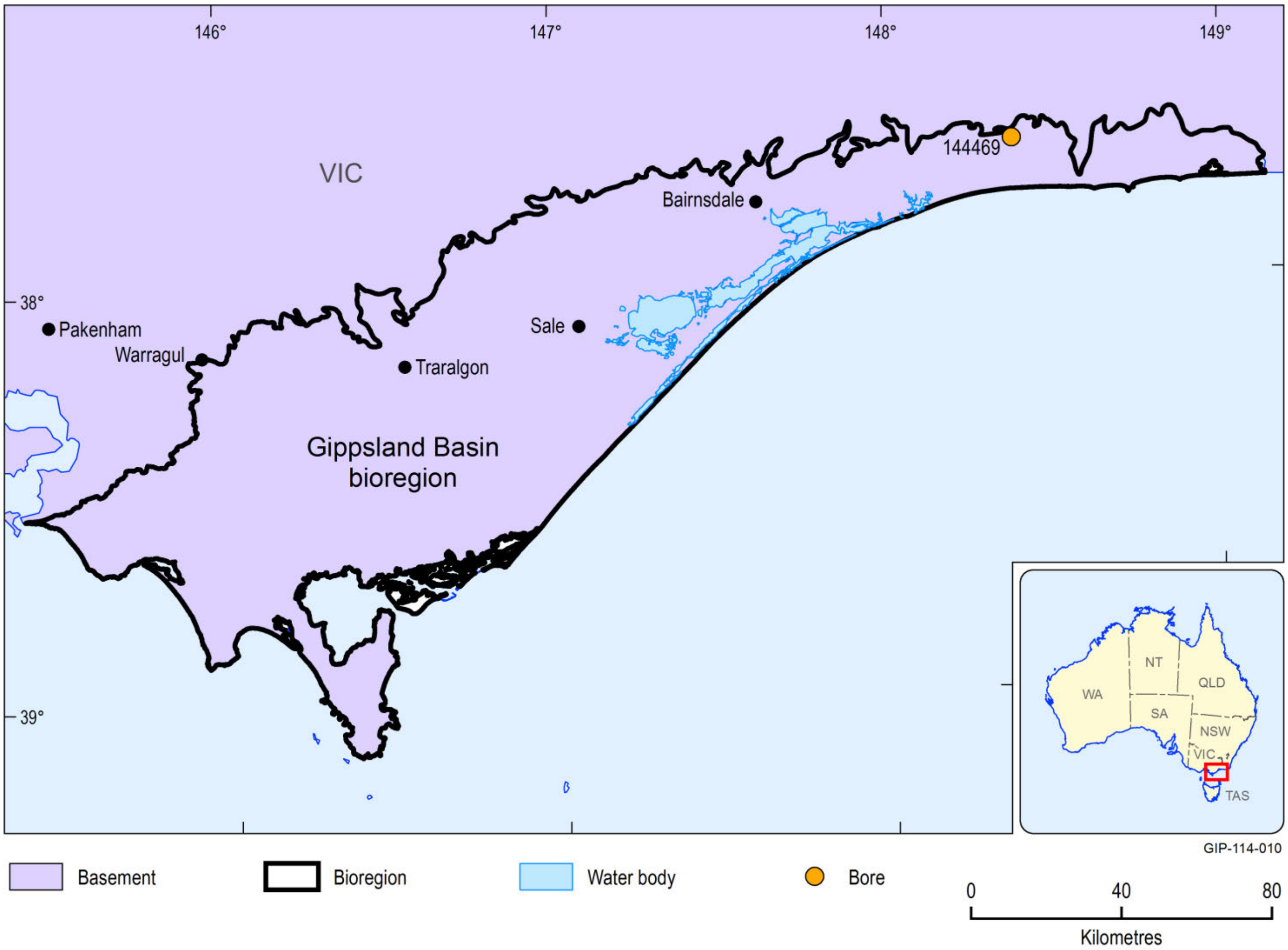
Upper aquifer system (Pleistocene to Holocene): Sale Group sediments

The Haunted Hills Gravel conformably overlies most of the Gippsland Basin. Recharge is via rainfall infiltration and river leakage. There is significant recharge to underlying aquifers of the Gippsland Basin via the Haunted Hills Gravel.

Recharge to the Quaternary dune and sand aquifers occurs via local rainfall infiltration. Recharge to the Quaternary alluvium of the Mitchell, Avon, Thomson, Macalister and Latrobe rivers is by river leakage, flood recharge and rainfall infiltration. In some areas, Quaternary aquifers discharge to the rivers, and the pattern of recharge and discharge relationships between the Quaternary aquifers and rivers is in many areas seasonal (Walker and Mollica, 1990). This will be discussed further in Section 1.1.6.

Aquifer depressurisation for coal mining and oil and gas development is not considered to have affected the groundwater levels of the Quaternary aquifers and the aquifers of the Haunted Hills Gravel (Nicol, 2010).

Figure 30 shows two representative hydrographs (bores 80762 and 105484) for the upper aquifer system which indicates there is no apparent influence of pumping from the underlying aquifers.



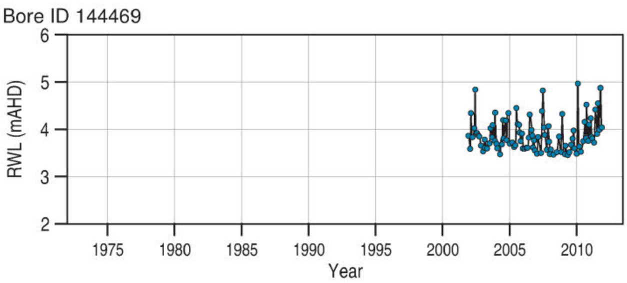


Figure 27 Basement aquifer system representative hydrograph. Elevation is in Relative Water Level (RWL) in mAHD

Data: Victorian Government (Dataset 3)

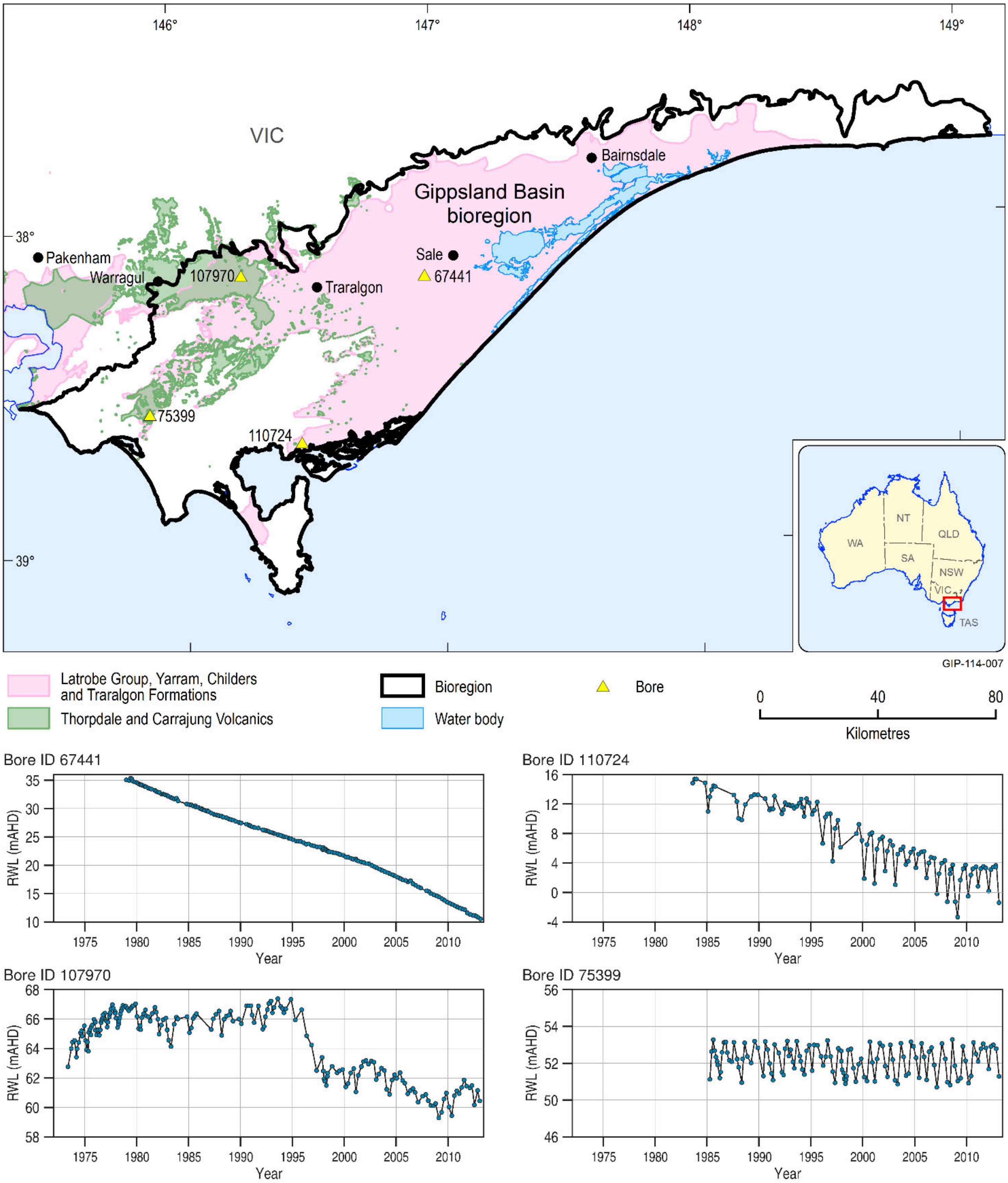


Figure 28 Lower aquifer system representative hydrographs. Elevation is in Relative Water Level (RWL) in mAHD

Data: Victorian Government (Dataset 3), Bureau of Meteorology (Dataset 4)

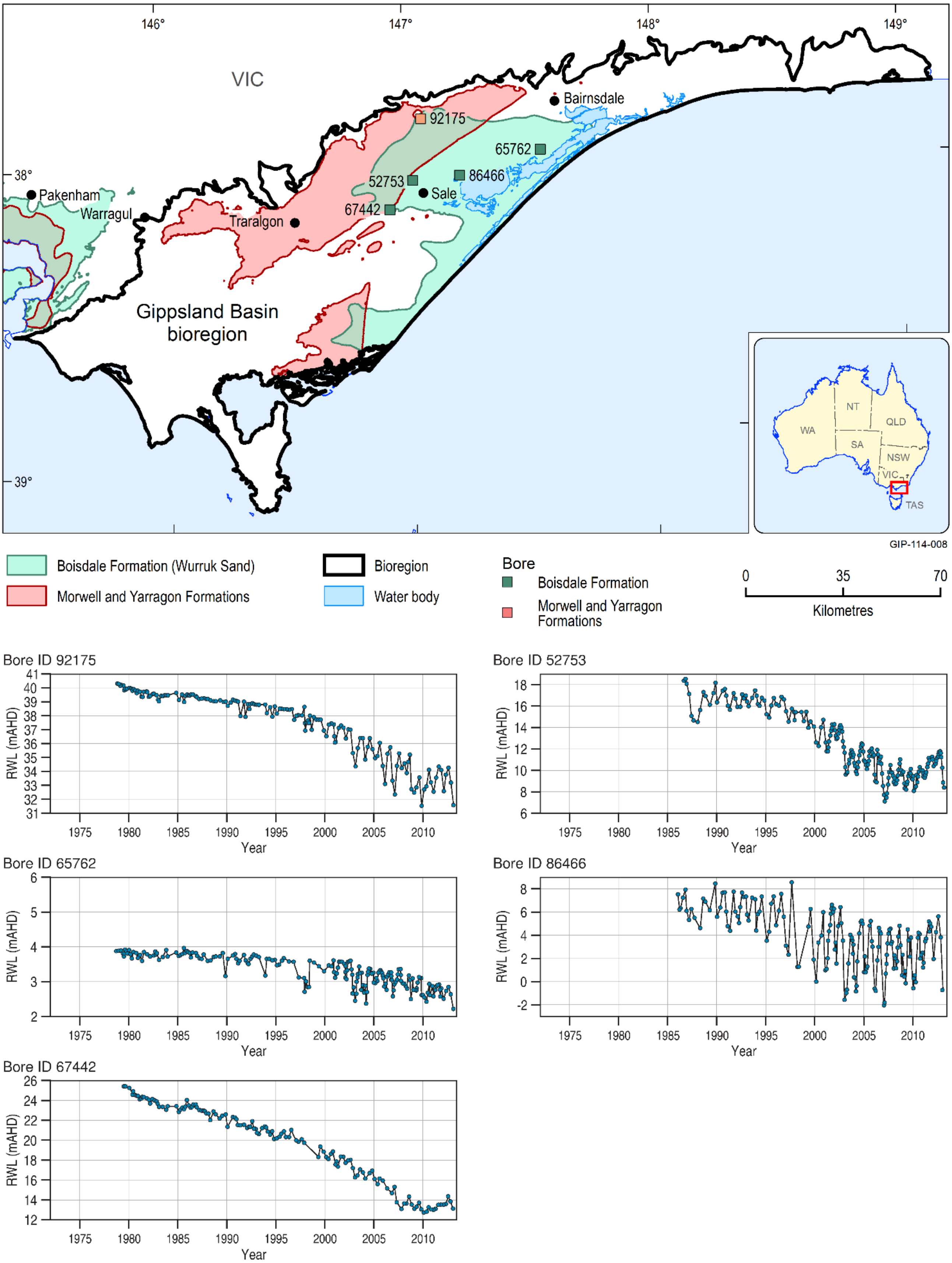


Figure 29 Middle aquifer system representative hydrographs. Elevation is in Relative Water Level (RWL) in mAHD

Data: Victorian Government (Dataset 3), Bureau of Meteorology (Dataset 4)

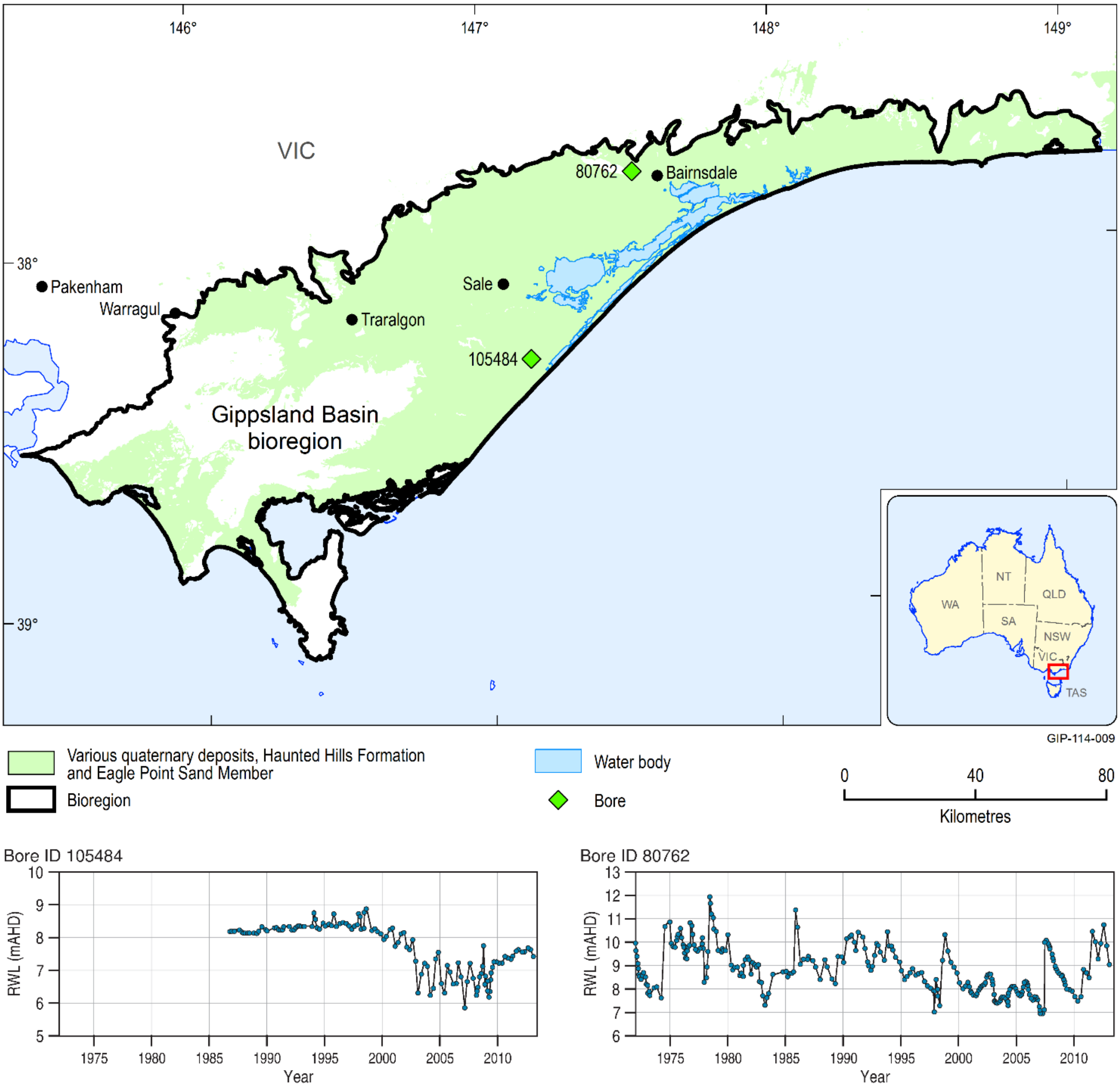


Figure 30 Upper aquifer system representative hydrographs. Elevation is in Relative Water Level (RWL) in mAHD

Data: Victorian Government (Dataset 3), Bureau of Meteorology (Dataset 4)

1.1.4.3.2 Tarwin sub-basin

The groundwater flow systems of the Tarwin sub-basin are isolated from those of the Gippsland Basin due to the structural controls on the basin. The Thorpdale Volcanics form the primary aquifer in the Tarwin sub-basin, and are considered to be in direct hydraulic connection with the overlying Haunted Hills Gravel, forming a largely unconfined aquifer (Nicol, 2010). Most groundwater flow is from the west and north-west to the south-east, where the Koorooman Fault largely forces groundwater to discharge upward into the Tarwin River as baseflow. Recharge largely occurs via rainfall infiltration to outcropping Haunted Hills Gravel, Thorpdale Volcanics, and Quaternary units (Nicol, 2010). Recharge may also occur as leakage from the Tarwin and Powlett rivers and their tributaries (Walker and Mollica, 1990). The Haunted Hills Gravel is considered to be in direct hydraulic connection with the Thorpdale Volcanics in the Tarwin sub-basin.

Aquifer depressurisation for coal mining and oil and gas development in the Gippsland Basin is not considered to have affected groundwater levels in the Tarwin sub-basin (Nicol, 2010). The majority of the groundwater extracted in the Tarwin sub-basin is from the volcanic aquifers. Figure 28 shows a representative hydrograph for the groundwater levels in the Tarwin sub-basin (bore 75399). Seasonal pumping influences are evident as well as the absence of trend. This likely reflects the limited storage of the volcanic aquifer and the relatively localised flow systems allowing for rapid drawdown and recovery via rainfall recharge.

1.1.4.3.3 Moe Swamp sub-basin

The sand, gravel and fractured basalt of the Childers Formation, Yarragon Formation and Thorpdale Volcanics are confined with artesian conditions occurring in the southern and central part of the basin. Low permeability layers are present within the sequence and potentiometric levels tend to increase with depth (Walker and Mollica, 1990). Recharge occurs where these formations outcrop in the north of the basin and in the south of the basin along the Yarragon Fault, and also to the Thorpdale Volcanics that outcrop in the west of the basin. Recharge is from stream leakage and rainfall infiltration, including leakage from the Latrobe River in the north of the Gippsland Basin (Brumley and Holdgate, 1983). Groundwater flow is from these recharge areas towards the centre and towards the east of the basin where groundwater discharges via upwards leakage through the confining beds in the east of the basin, up into the watertable aquifer and the Latrobe River (Nicol, 2010). This upward leakage occurs as a result of elevated basement topography on the Haunted Hills Block, in combination with the lateral facies change from sandy to clayey sediments around the Moe Monocline, which restricts groundwater flow eastwards out of the basin and into the Latrobe Valley (Brumley and Holdgate, 1983; Nicol, 2010).

Aquifer depressurisation for coal mining and oil and gas development in the Gippsland Basin is not considered to have affected groundwater levels in the Moe Swamp sub-basin. This is due to the restricted hydraulic connectivity between the Moe Swamp sub-basin and the Latrobe Valley Depression resulting from the structuring in the east of the Moe sub-basin (Nicol, 2010).

Brumley and Holdgate (1983) described the Moe Swamp sub-basin as being in a steady state and noted that under higher rates of groundwater extraction, the structural elements of the basin would play a stronger role in groundwater flow.

Figure 28 shows a representative hydrograph of groundwater levels in the Moe Swamp sub-basin aquifers (bore 107970). Apparently higher abstraction may be evident from 1997 onwards with hydrographs indicating a transition to slightly lower groundwater levels from this time onwards.

1.1.4.3.4 Groundwater connectivity

As previously discussed, there is potential for inter-aquifer connectivity and leakage in the Gippsland Basin (Hofmann and Cartwright, 2013), however there remain significant knowledge gaps on the location and volumes of inter-aquifer leakage. A map of the distribution of aquitards was produced to indicate those areas of the groundwater system with the most potential for inter-aquifer connectivity (Figure 31).

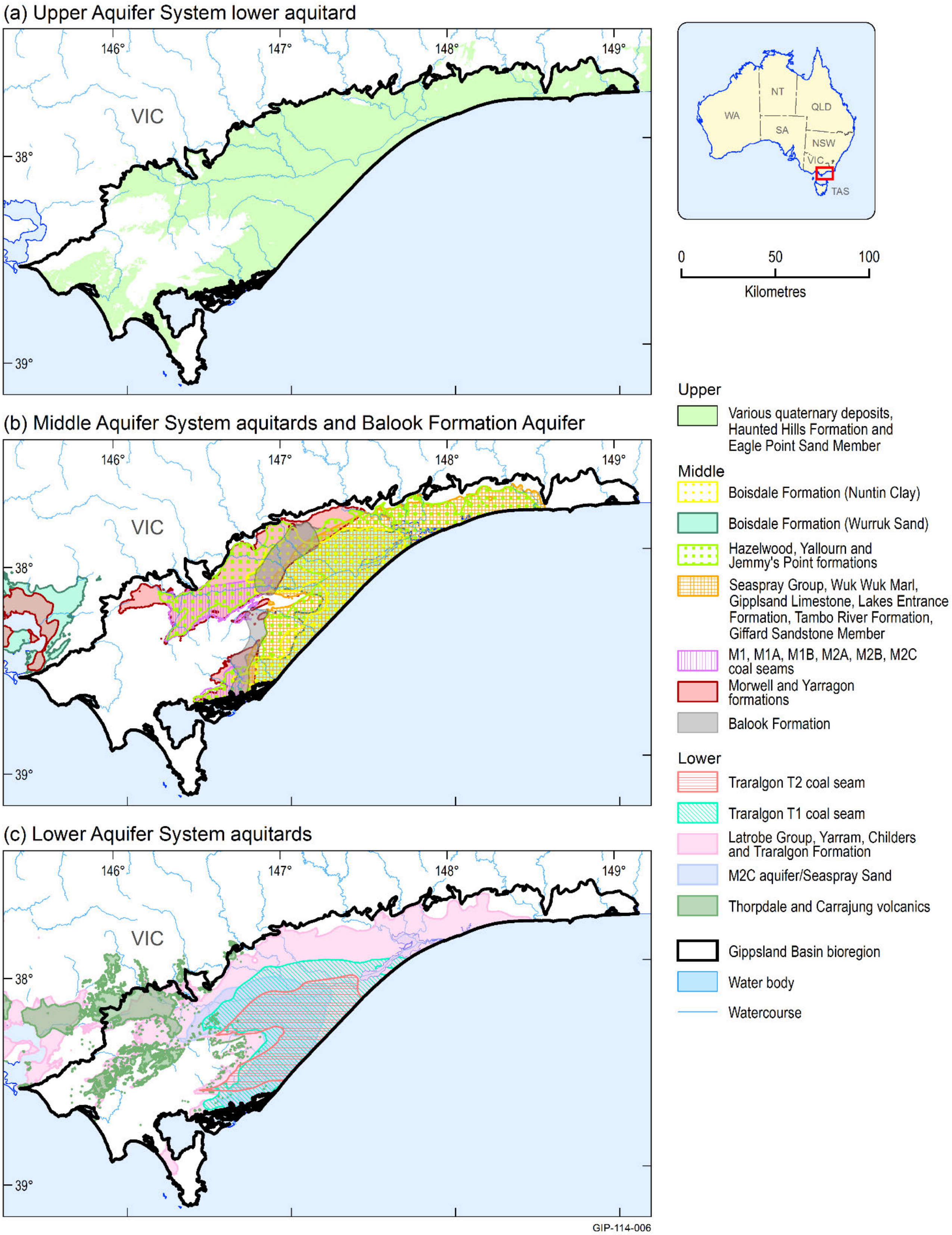


Figure 31 Distribution of aquifers and aquitards of the Gippsland Basin bioregion for (a) upper, (b) middle and (c) lower aquifer systems

Data: Victorian Government (Dataset 3), Victorian Government (Dataset 5), Bioregional Assessment Programme (Dataset 6), Bioregional Assessment Programme (Dataset 7)

1.1.4.4 Groundwater planning and use

Around 8% of the water extracted for towns, industry and agriculture in the Gippsland Basin bioregion is sourced from groundwater (DSE, 2011). The development of Gippsland's groundwater resources commenced in the early 1900s, with the development of the Macalister, Mitchell River and Yarram irrigation districts. Large-scale aquifer depressurisation for coal mining began in the 1960s. Groundwater from shallow and deep aquifers either supplies or supplements the water supply to a number of towns across Gippsland including Sale, Boisdale, Briagolong, Wurruk and Yarragon. Sale's town water supply has been solely sourced from groundwater since 1970 (Schaeffer, 2008). Groundwater has also become increasingly investigated as a contingency water supply for other towns throughout the Gippsland Basin (e.g. Thorpdale) (Gippsland Water, 2012).

There are about 164 GL of licensed groundwater entitlements in Gippsland. In any managed groundwater area, the licensed entitlement is capped at the permissible consumptive volume (PCV). The total PCV for the Gippsland Basin bioregion is about 176 GL (see Table 16).

The Yallourn, Morwell and Loy Yang open-cut coal mines hold licences to pump about 45 GL/year of groundwater to drain and stabilise the mines. Average annual groundwater extraction at the mines is 30 GL/year (DSE, 2011). The total extracted groundwater volume for the July 2012 to June 2013 period was 28.5 GL (GHD, 2013). This water is typically extracted from the middle aquifer system and the lower aquifer system.

Offshore oil and gas production extracts additional water from the Latrobe Group aquifer (the 'lower' groundwater system). The effective volume of oil, gas and groundwater extracted offshore is estimated at 100 GL/year since the early 1990s (DSE, 2011).

In general, water levels in the confined and semi-confined aquifers of the Gippsland Basin have been falling for the past few decades by around 0.5 m/year in parts of the Boisdale Formation, around 0.5 m/year in the Balook Formation and around 1.1 m/year in the Latrobe Group aquifers, while water levels in the shallow Quaternary age aquifers have remained steady.

Groundwater management is split into groundwater catchment areas:

- Central Gippsland groundwater catchment
- Moe groundwater catchment
- Seaspray groundwater catchment
- East Gippsland groundwater catchment
- Tarwin groundwater catchment.

Within these groundwater catchment areas, where there is more intensive groundwater use, groundwater is managed within groundwater management units (GMUs) called either water supply protection areas (WSPAs) or groundwater management areas (GMAs). Groundwater is managed in these GMUs under conditions set out by local management plans for each GMU. GMUs are defined by their depth and geographical boundaries which means that there may be more than one GMU overlapping in some areas. PCVs and trading rules are the principal management tools set out by these plans. Table 16 provides a summary of the management areas.

Figure 32 shows a map of the management areas. PCVs and licensed extraction volumes are included in Table 16.

Areas within groundwater catchments but outside a GMA or WSPA are managed under local management plans. No PCVs are set for local management plans outside WSPAs and GMUs. The following local management plans are in place:

- Central Gippsland and Moe Groundwater Catchments (areas outside of GMUs) Local Management Plan
- East Gippsland Groundwater Catchment (areas outside of the Orbost GMU) Local Management Plan
- Seaspray Groundwater Catchments (areas outside of GMUs) Local Management Plan
- Tarwin Groundwater Catchments (areas outside of GMUs) Local Management Plan.

All new licensed bores and any existing licensed bore with a licensed extraction volume of greater than 10 ML/year are metered.

Table 16 Water supply protection areas (WSPA) and groundwater management areas (GMU) within the Gippsland Basin bioregion

Water supply protection area or groundwater management area	Groundwater catchment	Victorian Aquifer Framework aquifer within groundwater catchment	Permissible consumptive volume (ML/year)	Licensed volume (entitlement) (ML/year)	Principal groundwater uses
Denison water supply protection area	Central Gippsland	Quaternary and upper Tertiary aquifer (AQ102)	18,502	17,743	Irrigation (73% entitlement), dairy cooling and wash down
Rosedale groundwater management area	Central Gippsland	Upper middle Tertiary aquifer (AQ107)	22,372	22,313	Irrigation (57% entitlement), power generation in the Latrobe Valley
Sale water supply protection area	Central Gippsland	Upper Tertiary (fluvial) AQ105)	21,238	21,212	Irrigation (82% entitlement), Sale town water supply
Stratford groundwater management area	Central Gippsland	Lower Tertiary aquifer (AQ111)	27,645	27,645	Irrigation (3% entitlement), power generation in the Latrobe Valley
Wa De Lock water supply protection area	Central Gippsland	Quaternary and upper Tertiary aquifer (AQ102)	30,795	30,172	Irrigation (84% entitlement), Briagolong and Boisdale town water supply
Wy Yung groundwater management area	Central Gippsland	Quaternary and upper Tertiary aquifer (AQ102)	7,463	7,463	Irrigation
Yarram water supply protection area	Central Gippsland	Lower Tertiary aquifer (AQ111)	25,690	25,317	Irrigation (80% entitlement), dairy cooling and wash down, other commercial and industrial use, Yarram town water supply
Giffard groundwater management area	Central Gippsland	Upper Tertiary (fluvial) AQ105)	5,689	5688.5	Irrigation

Water supply protection area or groundwater management area	Groundwater catchment	Victorian Aquifer Framework aquifer within groundwater catchment	Permissible consumptive volume (ML/year)	Licensed volume (entitlement) (ML/year)	Principal groundwater uses
Moe groundwater management area	Moe	Quaternary and upper Tertiary aquifer (AQ102) Upper Tertiary (fluvial) AQ105) Upper middle Tertiary aquifer (AQ107) Lower Tertiary aquifer (basalt) (AQ112) Lower tertiary aquifer (AQ111)	8,200	3,993	Irrigation (less than 70% entitlement), dairy cooling and wash down
Leongatha groundwater management area	Tarwin	Lower Tertiary aquifer (basalt) (AQ112) Lower Tertiary aquifer (AQ111)	6,500	1,840	Irrigation, dairy wash down, urban water supply
Tarwin groundwater management area	Tarwin	Quaternary and upper Tertiary aquifer (AQ102)	1,300	38	Irrigation, dairy wash down, urban water supply
Orbost groundwater management area	East Gippsland	Quaternary and upper Tertiary aquifer (AQ102)	1,217	1216.5	Irrigation (90% entitlement), dairy cooling and wash down
Total			176,611	164,641	

Source Southern Rural Water (2010; 2014a; 2014b; 2014c; 2014d)

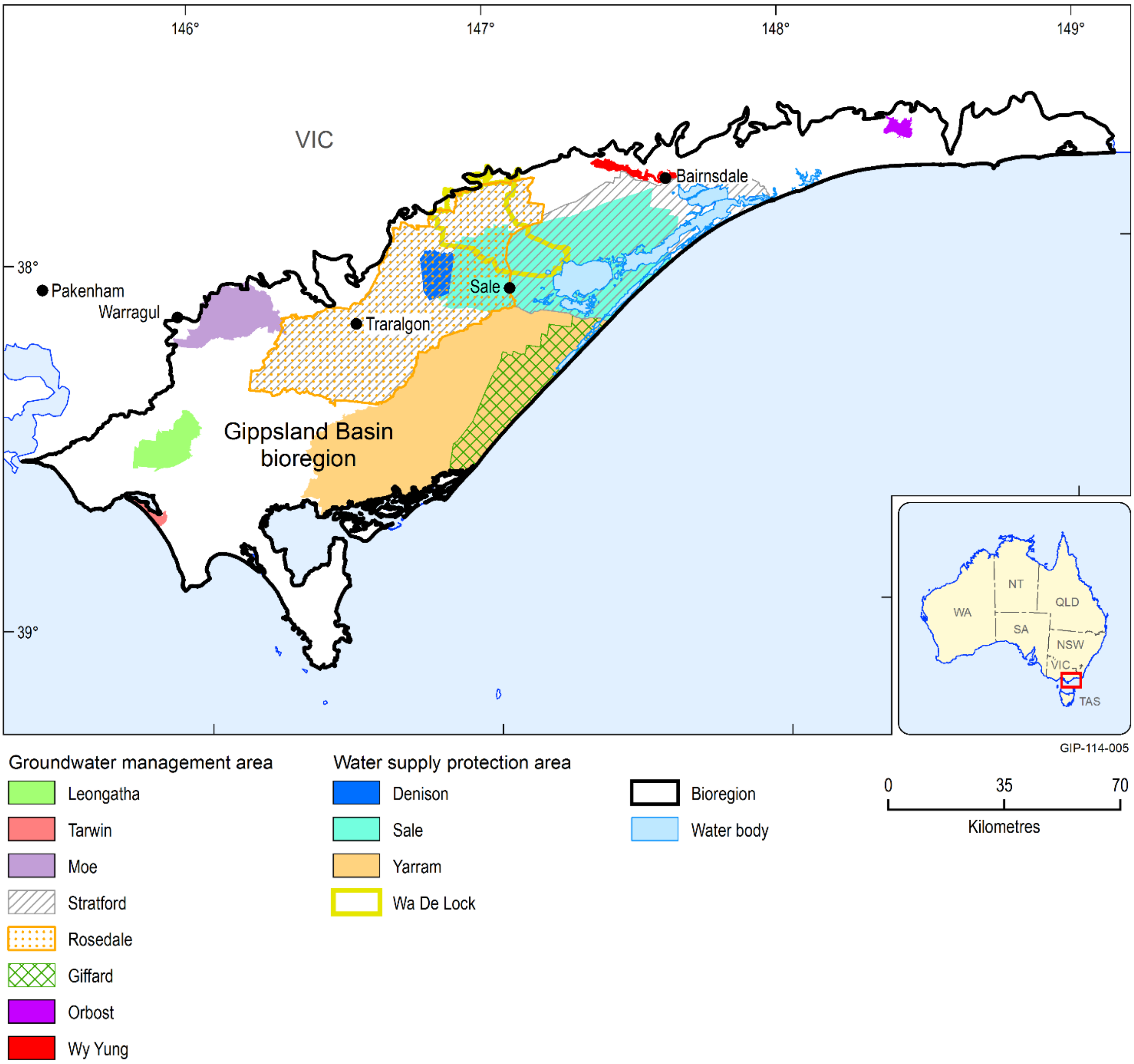


Figure 32 Groundwater management areas in the Gippsland Basin bioregion. Groundwater management areas cover most of the bioregion area

Data: Department of Environment and Primary Industries (Dataset 8), Department of Environment and Primary Industries (Dataset 9)

1.1.4.5 Groundwater monitoring and assessment

Groundwater levels are monitored throughout the Gippsland Basin bioregion by the Victorian Department of Environment and Primary Industries via the State Observation Bore Network. Intensive monitoring of groundwater levels in the Gippsland Basin began in the late 1970s to early 1980s. Recent statistical analysis and trend mapping has been undertaken for monitoring bores across Victoria, including within the Gippsland Basin. This mapping forms a useful basis for understanding trends within aquifer systems resulting from the various existing groundwater pumping stresses.

There have been several qualitative to semi-quantitative groundwater assessments for regions within the Gippsland Basin bioregion (Brumley and Holdgate, 1983; Hatton et al., 2004; Walker and Mollica, 1990). Several numerical groundwater models have been developed for various regions of the Gippsland Basin and for different purposes over the last two decades (Bolger, 1987; Bolger, 1990; Evans, 1983; Golder Associates Pty Ltd, 1992; Minchin, 2010; Nahm, 2002; Nicol, 2010; Schaeffer, 2008).

1.1.4.5.1 Latrobe Valley regional monitoring network

The Latrobe Valley regional groundwater monitoring network extends from Moe to Stratford. The majority of the monitoring bores monitor groundwater within the middle aquifer system and the lower aquifer system (GHD, 2013). Groundwater levels are monitored every six months. GHD (2013) stated that impacts to shallow aquifers (including the Boisdale aquifer) are typically limited by low permeability coals and clays within the middle and lower aquifer systems. There are 43 bores monitoring 87 intervals in the Morwell Formation and 67 bores monitoring 91 intervals within the Traralgon Formation. There are two bores within the underlying basement rocks and eight bores monitoring 16 intervals within the shallow aquifer system. One bore monitors groundwater levels in the Gippsland Limestone, south of Sale (GHD, 2013).

The rate of decline in hydraulic head in the lower aquifer (Traralgon Formation) is typically greater and more uniform than in the rate of decline in the middle aquifer (Morwell Formation) (GHD, 2013).

1.1.4.5.2 Primary Industries Research Victoria (PIRVIC) boreholes

These boreholes are typically monitored for salinity studies including parameters such as salinity and groundwater level (Nicol, 2010).

1.1.4.5.3 State Observation Bore Network

A network of monitoring bores is managed by the Victorian Department of Environment and Primary Industries across Victoria. Table 17 is a summary of the State Observation Bore Network monitoring bores in the Gippsland Basin. Bores are generally monitored on a monthly basis. The monitoring network has limited coverage within the Strzelecki Group. This may be a significant knowledge or data gap should any substantial unconventional gas development occur in the Strzelecki Group.

Table 17 State Observation Bore Network monitoring bores in the Gippsland Basin[1]

Aquifer system	Number of State Observation Bore Network monitoring bores	Groundwater management unit(s)
Bedrock	4	Orbost groundwater management unit, Moe groundwater management unit, unincorporated (East Gippsland), Rosedale groundwater management unit
Lower	52	Rosedale groundwater management unit, Yarram water supply protection area, Stratford groundwater management unit, Unincorporated (Central Gippsland, Moe, Tarwin), Moe groundwater management unit, Leongatha groundwater management unit, Tarwin groundwater management unit
Middle	31	Stratford groundwater management unit, Sale water supply protection area, Rosedale groundwater management unit, unincorporated (Central Gippsland), Yarram water supply protection area, Moe groundwater management unit, Denison water supply protection area
Upper	93	Orbost groundwater management unit, Wy Yung water supply protection area, Wa De Lock groundwater management unit, Denison water supply protection area, Giffard groundwater management unit, Sale water supply protection area, Rosedale groundwater management unit, Tarwin groundwater management unit, Yarram water supply protection area, unincorporated (Central Gippsland, Tarwin)

Source: GHD (2014)

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1.1.5 Surface water hydrology and water quality

Summary

The Gippsland Basin bioregion intersects four Australian Hydrological Geospatial Fabric (Geofabric, Bureau of Meteorology, 2013) River Regions: South Gippsland River Region, Mitchell–Thomson River Region, Snowy River Region and East Gippsland River Region. The area of the Gippsland Basin bioregion is 14,636 km^2 of which 52% is included in the Mitchell–Thomson River Region followed by 39% in the South Gippsland River Region, 7% in the Snowy River Region and 2% in the East Gippsland River Region.

The south-western part of the Gippsland Basin bioregion is part of the South Gippsland River Region. The surface water systems of this river region include several rivers (e.g. Tarwin River, Albert River and Tarra River) and creeks (e.g. Merriman Creek and Bruthen Creek) as well as freshwater and salinewater wetlands. A notable feature of the system is its floodplain providing rich agricultural land as well as areas of high conservation value, such as Wilsons Promontory, Corner Inlet and the Nooramunga Marine and Coastal Park. Major watercourses in this river region originate within the Gippsland Basin bioregion and discharge to inlets through to the ocean. The majority of them are unregulated. There have been a number of large flood events (e.g. in 1934, 1990, 2011 and 2012). Streamflow in the South Gippsland River Region has not yet been affected by major diversions or storages. Irrigation is not widespread due to the relatively reliable rainfall all across the river region. Water quality indicators such as electrical conductivity (EC) and turbidity are very high in part of the river region compared to other river basins in the Gippsland Basin bioregion. However, these are still within water quality objective values for the South Gippsland River Region.

Much of the Gippsland Basin bioregion overlaps the Mitchell–Thomson River Region. The surface water systems of this river region include several large rivers including the Latrobe River, Thomson River, Macalister River, Mitchell River and Tambo River as well as wetlands and saltwater pans. In the north, river basins are characterised by the naturally forested Eastern Highlands. The lower part of the river region features cleared agricultural land. The majority of the watercourses in this river region are unregulated, except for the lower parts of the Latrobe River, Thomson River and Nicholson River. The amount of flow regulation on most of these systems is however relatively small. A large proportion of available surface water in this river region is allocated for the environment, with the remainder allocated through bulk entitlements and licensed diversions. Water quality indicators vary between watercourses; however, both EC and turbidity are within the limits of water quality objectives.

A small proportion of the Gippsland Basin bioregion is located in the Snowy River Region. The surface water system of this river region includes several large rivers and creeks as well as wetlands on the floodplain. In the north, the river region is characterised by the naturally forested Eastern Highlands. All major watercourses in this river region originate outside the Gippsland Basin bioregion and discharge to the sea. The watercourses in the Snowy River Region are unregulated, except for the Snowy River. There have been a number of significant flood events including in 1964, 1970, 1983, 1991, 2007, 2011 and 2012. Streamflow in the

Snowy River Region has been affected by dams and diversions. There is a significant reduction in river flow after the construction of four large dams in the mid-20th century as part of the Snowy Mountains Scheme. Water quality for major watercourses in the Snowy River Region is generally good. Both EC and turbidity are less than the trigger values of 500 µS/cm and 10 NTU (Nephelometric Turbidity Unit) respectively.

The eastern end of the Gippsland Basin bioregion is part of the East Gippsland River Region. The surface water system of the river region includes four large rivers and several creeks as well as freshwater and salinewater wetlands. Consistent with the high proportion of naturally forested land and the absence of major water storages, the majority of the streams in this river region maintain natural or near natural flow regimes. There have been a number of significant flood events in the past. The most recent major flood events occurred in the river region in 1990, 1998 and 2007. A number of lesser floods also occurred through this period, including those in 2010 and 2011. Water quality indicators for all major watercourses in the East Gippsland River Region are relatively good. The EC values are much lower than the water quality objective trigger value. Turbidity lies within the acceptable range.

1.1.5.1 Surface water systems

The surface water management units defined in this section conform to the major river regions delineated in the Bureau of Meteorology Geofabric dataset (Bureau of Meteorology, 2013). According to Bureau of Meteorology's Geofabric data, the surface water systems in the Gippsland Basin bioregion are part of four river regions in the state of Victoria. These are South Gippsland, Mitchell–Thomson, Snowy and East Gippsland as shown in Figure 33. The major watercourses within these river regions and their topological relationships with each other are presented in Figure 34. Details of each of these four river regions are presented in the following sections.

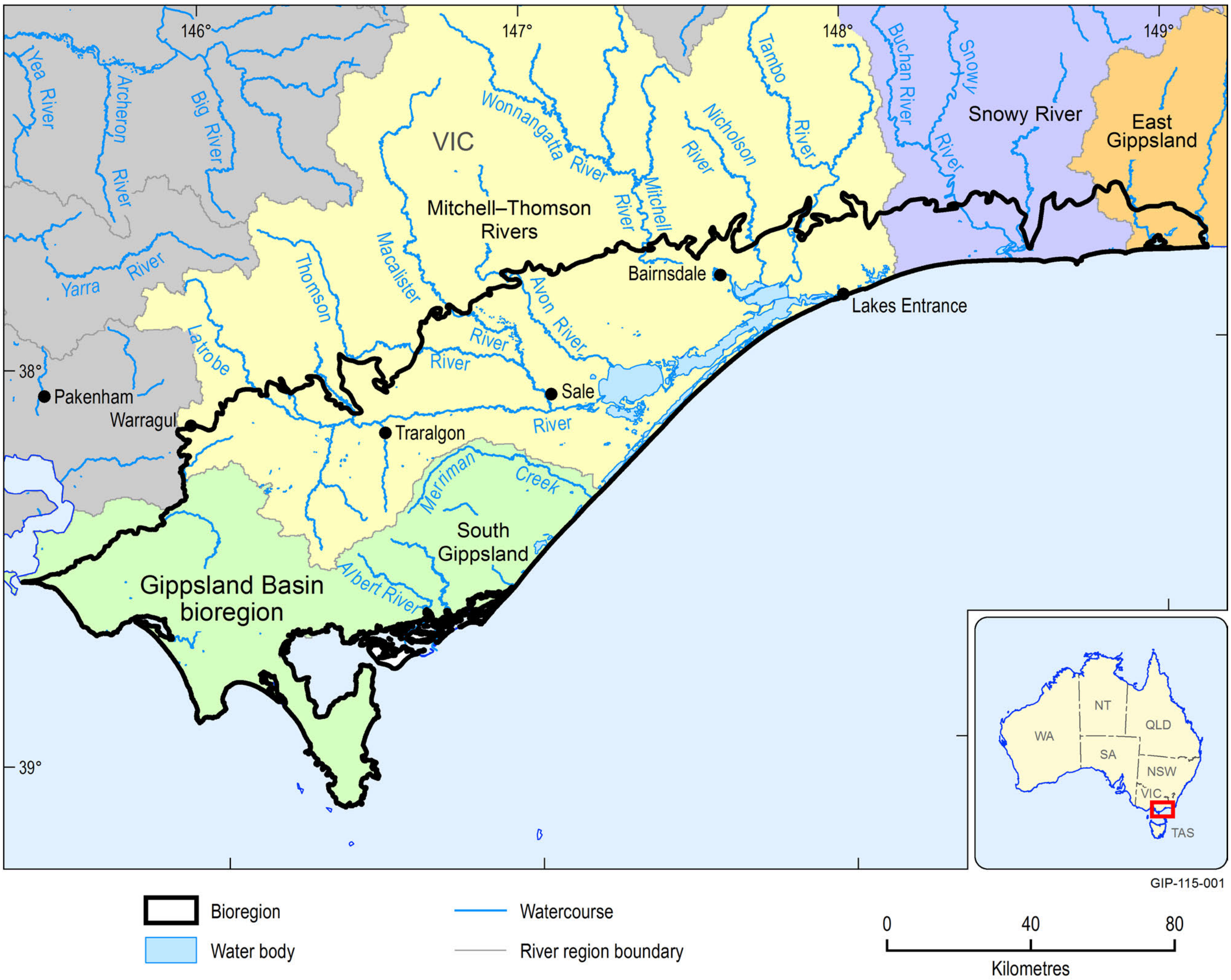

Figure 33 Location of the Gippsland Basin bioregion, town centres and major watercourses, and associated nearby Geofabric river regions

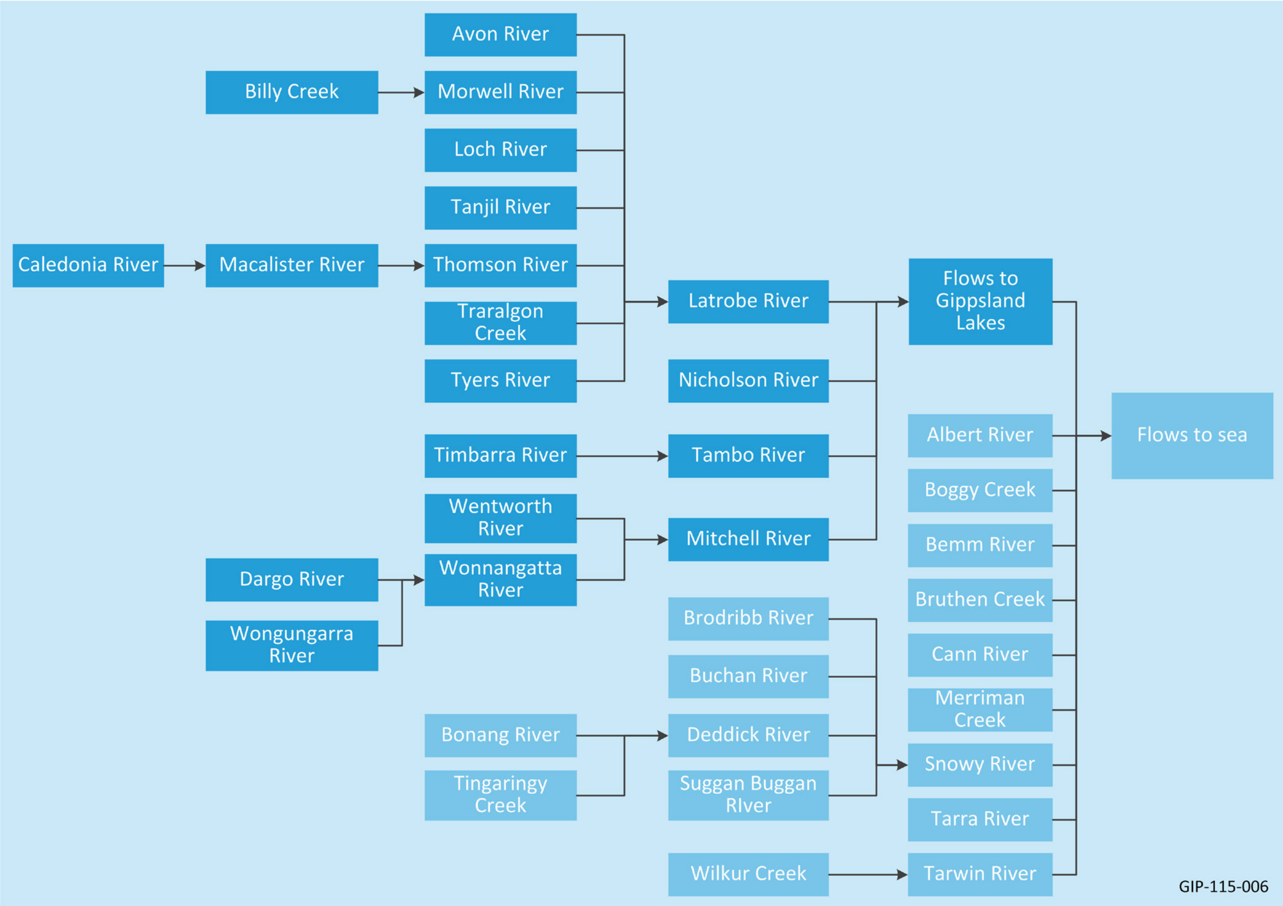

Figure 34 Schematic representation of major watercourses and their inter-linkages with each other in the Gippsland Basin bioregion

1.1.5.1.1 South Gippsland River Region

The South Gippsland River Region is located in the south-west of the Gippsland Basin bioregion. It has a drainage area of 6202 km^2. The major surface water systems include the Albert, Tarra and Tarwin rivers and Merriman and Bruthen creeks, as well as freshwater and salinewater wetlands (Figure 35). A notable feature of the system is its floodplain providing rich, agricultural land as well as areas of high conservation value, such as Wilsons Promontory, Corner Inlet and the Nooramunga Marine and Coastal Park. About 92% of the river region area is included in the Gippsland Basin bioregion and makes up 39% of the bioregion.

The majority of watercourses in this river region originate within the Gippsland Basin bioregion and discharge to inlets (e.g. Anderson, Corner) through to the ocean. The majority of the watercourses in the South Gippsland River Region are unregulated; only Coalition and Lance creeks in the western part of the river region are regulated. Almost three-quarters (74%) of the streams in the South Gippsland River Region are in moderate condition. Of the remainder, 10% are in good condition, 10% are in poor condition and 5% are in very poor condition (Department of Environment and Primary Industries, 2013a). There have been a number of significant flood events in the South Gippsland River Region including in 1934, 1990, 2011 and 2012. Often short duration and high intensity rainfall causes flash flooding throughout the South Gippsland River Region. Moderate to heavy rainfall, coupled with a high or incoming tide or storm surge associated with an extreme low pressure system can exacerbate flooding in the coastal areas.

Streamflow in the South Gippsland River Region has not yet been affected much by diversion of water. There are no large regulated supply systems and irrigation is not widespread due to the relatively reliable rainfall. However, there are some storages and pump stations of small to medium capacity across the river region.

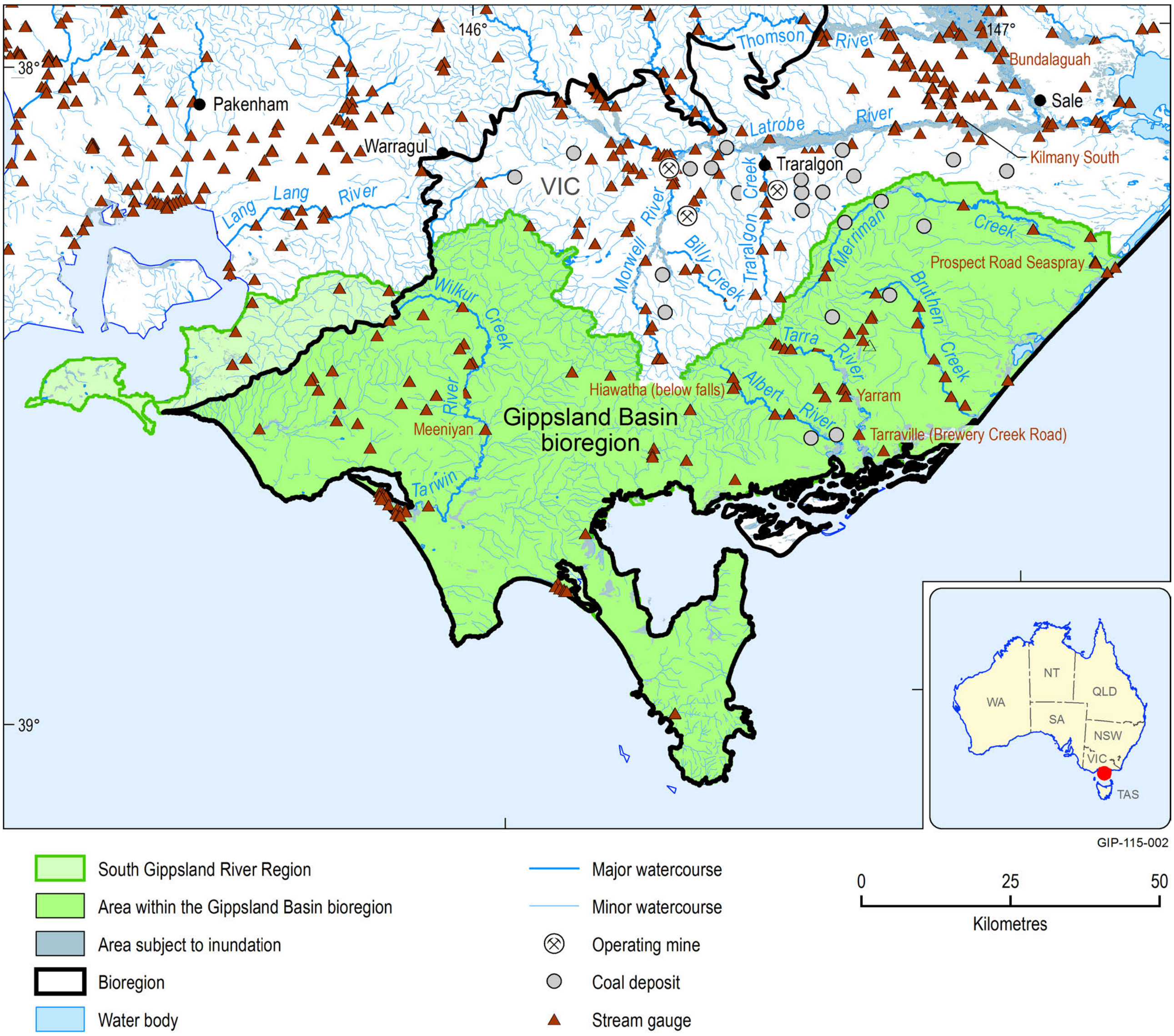

Figure 35 South Gippsland River Region showing major rivers, water assets, lands subject to inundation and location of mining development for the Gippsland Basin bioregion

Data: Bioregional Assessment Programme (Dataset 1), Department of Environment and Primary Industries (Dataset 2), Geoscience Australia (Dataset 3), Bureau of Meteorology (Dataset 4)

1.1.5.1.2 Mitchell–Thomson River Region

The Mitchell–Thomson River Region covers the central part of Gippsland Basin bioregion. It has a combined drainage area of 21,091 km^2. Several large rivers including the Latrobe, Thomson, Mitchell, Tambo and Nicholson rivers are part of this river region. The surface water systems also include several creeks and wetlands (Figure 36). In the north, the river region is characterised by the naturally forested Eastern Highlands. The lower part of the river region features cleared agricultural land and flow to Gippsland Lakes in the east. The Latrobe, Thomson, Macalister, Avon, Mitchell, Nicholson and Tambo rivers all flow into the Gippsland Lakes through a varied landscape which includes open-cut coal mines, power generation plants, timber harvesting and paper production, major water storages, Ramsar wetlands and agricultural pursuits including irrigation, horticulture and grazing. Although much of the land has been cleared for agriculture, there are significant mining activities for brown coal used at Loy Yang, Hazelwood and Yallourn power stations. About 36% of the river region area is included in the Gippsland Basin bioregion and this makes up 52% of the bioregion area.

All the major watercourses in the Mitchell–Thomson River Region originate outside the Gippsland Basin bioregion and discharge to the Gippsland Lake (Figure 36). The majority of them are unregulated except for the lower parts of the Latrobe, Thomson and Nicholson rivers. The amount of flow regulation on most of these systems is however relatively small. The hydrological condition of streams across the catchment reflects the varied land use - from natural and near natural flow regimes in headwater streams in forested areas of the region to flow regimes under immense stress in areas dependent on water supply for domestic and agricultural use. One-third (34%) of the streams in the Latrobe river basin are in good or excellent condition, with a further 44% in moderate condition. Over half (55%) of the streams in the Thomson river basin are in good or excellent condition and about 41% are in moderate condition (Department of Environment and Primary Industries, 2013a). There have been a number of large flood events in the Mitchell–Thomson River Region including in 1964, 1970, 1983, 1991, 2007, 2011 and 2012. These events have caused significant infrastructure and property damage in the past.

Flow in the Mitchell–Thomson River Region has been affected by dams and diversion of water. There is a large dam on the Thomson River (1068 GL capacity), a small dam on Nicholson River (640 GL capacity), and two small reservoirs (Department of Environment and Primary Industries, 2014a). A large proportion of available surface water in this basin is allocated for the environment with the remainder allocated through bulk entitlement and licensed diversions.

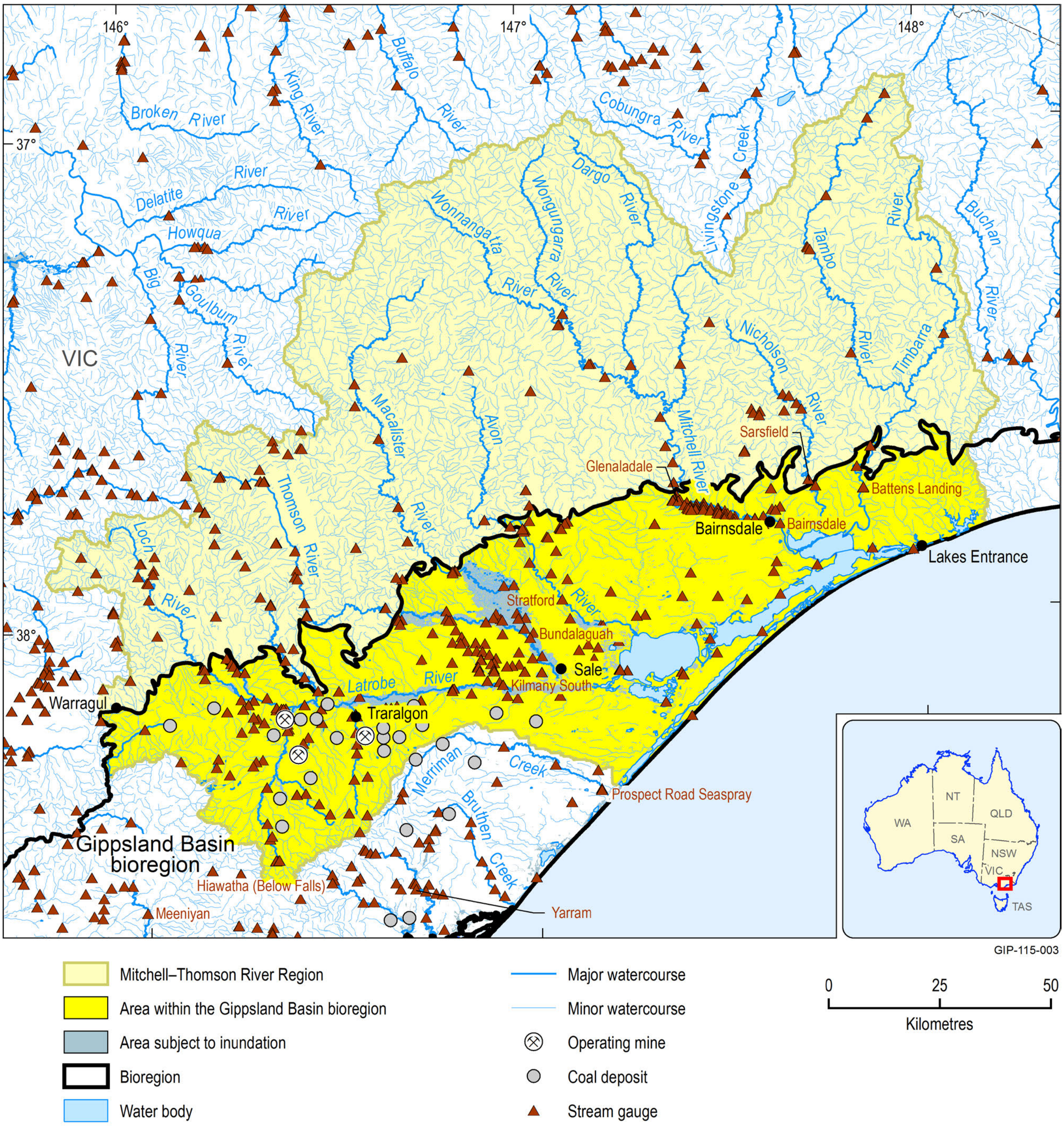

Figure 36 Mitchell–Thomson River Region showing major rivers, water assets, lands subject to inundation and location of mining development for the Gippsland Basin bioregion

Data: Bioregional Assessment Programme (Dataset 1), Department of Environment and Primary Industries (Dataset 2), Geoscience Australia (Dataset 3), Bureau of Meteorology (Dataset 4)

1.1.5.1.3 Snowy River Region

The Snowy River Region covers a small proportion of the Gippsland Basin bioregion in the east. It has a drainage area of 15,767 km^2. The surface water systems include the Eucumbene, Delegate and Jacobs rivers in the upper river region and Deddick, Buchan and Brodribb rivers in the downstream part of the river region, as well as wetlands on the floodplain (Figure 37). In the north, the river region is characterised by the naturally forested Eastern Highlands. About 6% of the river region area is included in the Gippsland Basin bioregion and makes up about 7% of the bioregion area.

The Snowy River is one of the major watercourses in south-eastern Australia. It originates on the slopes of Mount Kosciuszko, draining the eastern slopes of the Snowy Mountains in NSW, before flowing through the Alpine National Park and the Snowy River National Park in Victoria and emptying into Bass Strait. Major watercourses in this river region originate outside the Gippsland Basin bioregion and discharge to the mouth of the Snowy River through to the sea. The watercourses in this river region are unregulated except for the Snowy River. The hydrological conditions of streams across the catchment reflect from natural and near natural flow regimes in headwater streams in forested areas of the region to flow regimes under immense stress in areas dependent on water supply for domestic and agricultural usage (Department of Environment and Primary Industries, 2013a). There have been a number of significant flood events in the Snowy River Region including in 1971, 1978, 1988, 2007, 2011 and 2012 (Department of Environment and Primary Industries, 2012).

Streamflow in the Snowy River Region has been affected by large dams and diversions. Flow was greatly reduced in the mid-20th century after the construction of four large dams at Guthega, Island Bend, Eucumbene and Jindabyne and many smaller diversion structures in its headwaters in NSW, as part of the Snowy Mountains Scheme (Department of Environment and Primary Industries, 2014a).

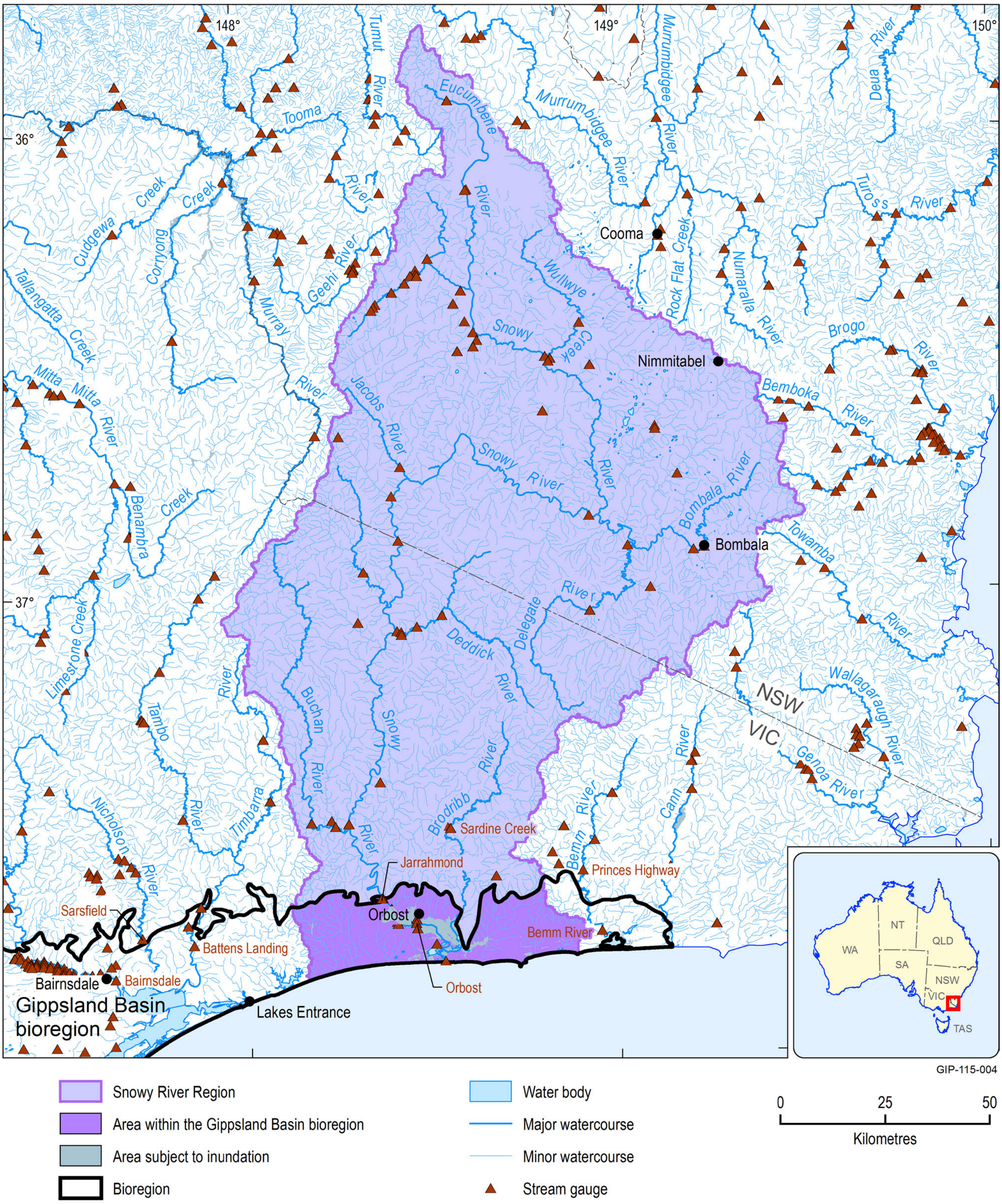

Figure 37 Snowy River Region showing major rivers, water assets, lands subject to inundation and location of mining development for the Gippsland Basin bioregion

Data: Bioregional Assessment Programme (Dataset 1), Bureau of Meteorology (Dataset 4)

1.1.5.1.4 East Gippsland River Region

The East Gippsland River Region is located in the eastern end of the Gippsland Basin bioregion. It is a relatively small river region compared to other river regions in Gippsland and it covers only a small proportion of the Gippsland Basin bioregion. It has a drainage area of 5670 km^2. The surface water system includes four large rivers and several creeks, as well as freshwater and salinewater wetlands (Figure 38). The Bemm River is listed as a Heritage River for the presence of rainforest, significant habitat, native fish diversity and the connection to Sydenham Inlet. The Upper Genoa River is also listed as a Heritage River based on the geological/geomorphological significance of the Genoa River gorge, scenic landscapes and sites of botanical significance. About 5% of the river region area is included in the Gippsland Basin bioregion and makes up about 2% of the bioregion area.

The main rivers in the East Gippsland River Region are the Bemm, Cann and Genoa rivers, all of which flow south or south-east into coastal inlets or lagoons, before entering the sea. Only the Bemm and Cann rivers flow to the Gippsland Basin bioregion. The watercourses in this river region are unregulated except for some small diversion weirs. The hydrological condition of streams varies across the East Gippsland River Region. Consistent with the high proportion of naturally forested land and the absence of major water storages, most streams in this river region maintain natural or near natural flow regimes (Department of Environment and Primary Industries, 2013a). There have been a number of large flood events in the East Gippsland River Region. The most recent major flood events occurred in the region in 1990, 1998 and 2007. A number of lesser floods also occurred through this period, including those in 2010 and 2011.

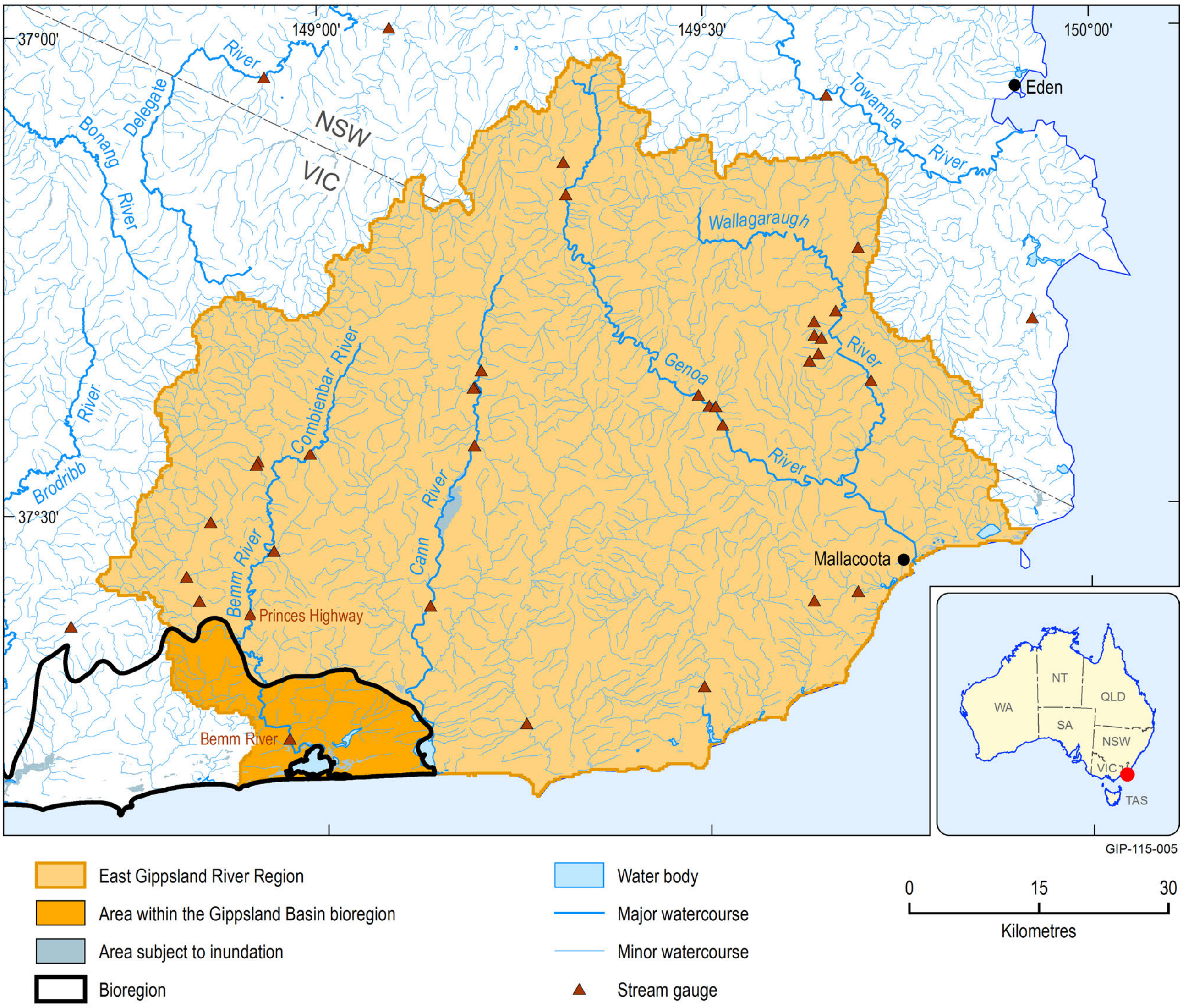

Figure 38 East Gippsland River Region showing major rivers, water assets and lands subject to inundation for the Gippsland Basin bioregion

Data: Bioregional Assessment Programme (Dataset 1), Bureau of Meteorology (Dataset 4)

1.1.5.2 *Surface water quality*

The Department of Environment and Primary Industries (DEPI) of the Victorian Government monitors and reports the water quality across Victoria's water resources including the river basins that are part of Gippsland Basin bioregion through a number of programmes and partnerships. The Water Measurement Information System (Department of Environment and Primary Industries, 2015) is the primary access point to search, discover, access and download water quality data collected by DEPI and its partners. Waterwatch Victoria (Waterwatch Victoria, 2015) is one of the DEPI's partner organisations and monitors water quality and river health through a community engagement programme connecting local communities with river health and sustainable water issues and management. The water quality indicators included in this report are EC and turbidity and results are based on variable data periods for different river basins.

Water quality indicators for the rivers in the Gippsland Basin bioregion were evaluated against the water quality objective trigger value provided by the Environment Protection Authority (EPA) of the Victorian Government. In general EC levels are low and stable across the bioregion but subject to occasional high pulses at some gauging sites. Turbidity is high and subject to varying trends as a result of local influences. It appears turbidity decreases from upstream to downstream of the catchments. The 75th percentile water quality objective value for EC for most of the Gippsland Basin bioregion is 500 µS/cm while for the forested parts in the upper catchments it is 100 µS/cm. The water quality objective value for turbidity is 5 NTU for the East Gippsland River Region and it is 10 NTU for the rest of the Gippsland Basin bioregion (EPA, 2003). It is mentioned here that the surface water and groundwater of Victoria are currently being reviewed and this may change the current water quality objectives.

Both EC and turbidity are very high in parts of the South Gippsland River Region compared to other river regions in the Gippsland Basin bioregion. Department of Environment and Primary Industries (2013b) shows that EC values at Meeniyan on the Tarwin River are close to 500 µS/cm and there is an increasing trend since 2005. Turbidity values are also much higher compared to the trigger value, reaching up to 92 NTU. However, not all watercourses exceed trigger values in this river region. For example, the mean and median EC values at Tarraville on the Tarra River are 255 and 245 µS/cm, respectively. Turbidity for this station varies between 0.9 and 24.7 NTU with mean and median of 6.0 and 4.6 NTU, respectively.

Across the Mitchell–Thomson River Region, both EC and turbidity vary greatly between watercourses. At Glenaladale on the Mitchell River the EC varies between 40 and 150 µS/cm with mean and median of 78 and 74 µS/cm, respectively. Turbidity at the same site varies between 0.7 and 5.4 NTU with mean and median of 2.1 and 1.8 NTU, respectively. The mean and median EC values for the Thomson River at Bundalaguah are 118 and 120 µS/cm, which are relatively high compared to those found in the Mitchell River. However, these values are still much smaller than the trigger value. The turbidity for the Thomson River is very high with mean and median of 27.3 and 18 NTU, respectively. Water quality of these river systems is particularly important as they discharge catchment runoff to the Gippsland Lakes which is listed as a Ramsar Site.

Water quality for major watercourses in the Snowy River Region is generally good. An analysis based on observed data at Orbost station on the Snowy River for the period of 1991 to 1998 (95 readings) shows that EC varies between 56 and 556 µS/cm with mean and median of 160 and 145 µS/cm, respectively. The mean and median turbidity for the same site (95 data) are 5.4 and 2.5 NTU, respectively.

Water quality indicators for all major watercourses in the East Gippsland River Region are relatively good. The EC values in this river region are generally much lower than the water quality objective trigger value of 500 µS/cm. An analysis based on observed data at Princes Highway on the Bemm River (GS 221212) for the period of 1991 to 2013 (292 readings) shows that EC values are in the range of 18 to 320 µS/cm (mean: 79, median: 76) which is much less than the trigger value. Turbidity for the same site (268 data) varies between 0.4 and 73.0 NTU with mean and median of 5.5 and 3.2 NTU, respectively.

There have been three studies that have analysed long-term trends in river water quality across Victoria. The first water quality trend report was published in 1998 and the second in 2007. The Victorian Water Quality Trends 1991–2010 is the third long-term assessment of trends in water quality and focuses specifically on changes in water quality before and after 2005. Water quality is strongly influenced by local conditions and events, such as rainfall, runoff, floods and bushfires. As a result, water quality is inherently variable but is only of concern when results are consistently outside the expected natural variability. Department of Environment and Primary Industries (2013b) shows EC generally increased across the Gippsland Basin bioregion after June 2005 but the increases are relatively small. Turbidity has also increased after June 2005, but the increases at most sites are not likely to be environmentally significant. Individual instances of high turbidity were recorded at sites in several Gippsland rivers during or soon after large floods (Department of Environment and Primary Industries, 2013b).

1.1.5.3 Surface water flow

The surface water flow in the Gippsland Basin bioregion originates from four river regions (South Gippsland, Mitchell–Thomson, Snowy and East Gippsland) by its numerous headwater streams. Each of these river regions are characterised by large variations in discharge and flow duration. There are a large number of streamflow monitoring stations across the Gippsland Basin bioregion. A list of end-of-system stream gauges for major watercourses in the Gippsland Basin bioregion along with mean annual flow (MAF) and mean annual runoff (MAR) is given in Table 18. Details of the streamflow characteristics of different river regions that are included in the Gippsland Basin bioregion are described in the subsequent sections.

Table 18 List of stream gauges in the Gippsland Basin bioregion located in four river basins that are part of Gippsland Basin bioregion hydrological study

Gauge number	Name of stream gauge	River Region	Catchment area (km^2)	Mean annual flow (GL)	Mean annual runoff (mm)	Data period
GS 221225	Bemm River upstream of pump house	East Gippsland	935	122	131	1966–1975 and 2009–present
GS 223209	Tambo River at Battens Landing	Mitchell–Thomson	2,781	206	74	1977–present
GS 223210	Nicholson River at Sarsfield	Mitchell–Thomson	471	41	87	1997–present
GS 224200	Mitchell River at Bairnsdale	Mitchell–Thomson	4,425	331	75	1889–present
GS 225201	Avon River at Stratford	Mitchell–Thomson	1,485	162	109	1976–present
GS 225232	Thomson River at Bundalaguah	Mitchell–Thomson	3,538	373	105	1976–present
GS 226227	Latrobe River at Kilmany South	Mitchell–Thomson	4,464	502	112	1976–present
GS 222200	Snowy River at Jarrahmond	Snowy River	13,420	912	68	1889–present
GS 227200	Tarra River at Yarram	South Gippsland	215	32	151	1946–present
GS 227201	Bruthen Creek at Woodside	South Gippsland	174	29	166	1946–1960
GS 227202	Tarwin River at Meeniyan	South Gippsland	1,067	254	238	1955–present
GS 227216	Albert River at Hiawatha (Below Falls)	South Gippsland	41	14	337	1964–1989
GS 227240	Merriman Creek at Prospect Road Seaspray	South Gippsland	529	28	52	1983–present

Source: Department of Environment and Primary Industries (2014b). Mean annual flow statistic sourced from Bureau of Meteorology (2014)

Water in the South Gippsland River Region is derived from several small river catchments within the bioregion. The average runoff varies from 52 mm for the Merriman Creek at Prospect Road Seaspray to 254 mm for the Tarwin River at Meeniyan. Although most streams in the South Gippsland River Region are perennial, streamflow varies between years and months. Figure 39 shows an example of yearly and monthly flow distribution based on observed streamflow at Meeniyan for the period of 1989 to 2013. MAF between the periods from 1989 to 2013 varies from 65 to 457 GL with a mean of 235 GL. Mean monthly flow varies from 2.5 to 51 GL with about 84% of the annual flow occurring from June to October.

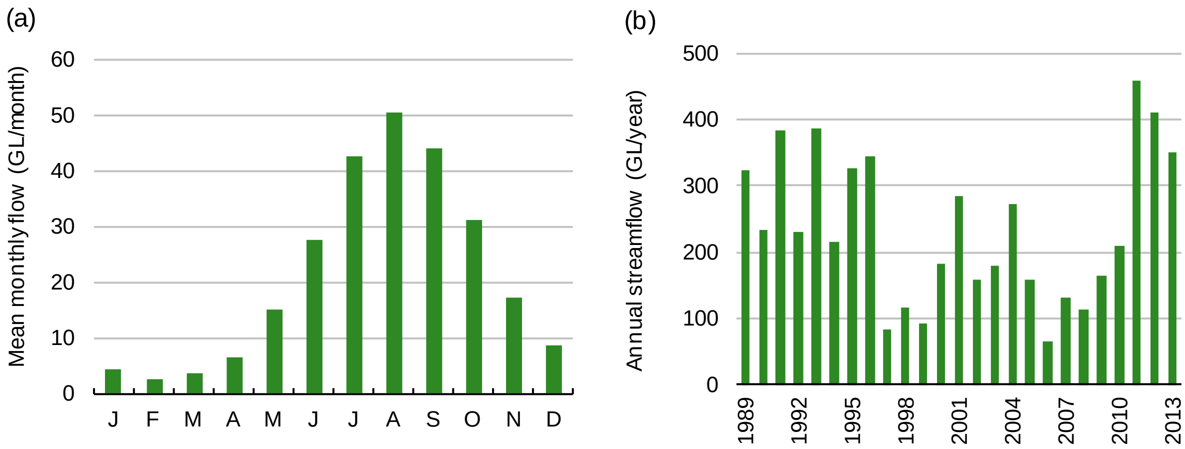

Figure 39 Flow distribution at Meeniyan on the Tarwin River in South Gippsland River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:227202)

Data: Bioregional Assessment Programme (Dataset 5)

Water in the Mitchell–Thomson River Region is predominantly derived from runoff from headwater catchments. The average runoff across the river region varies from 41 mm for the Nicholson River at Sarsfield to 502 mm for the Latrobe River at Kilmany South. Streamflow in Mitchell–Thomson River Regions varies between years from very small flow to large flooding, and between months. Figure 40 shows an example of yearly and monthly flow distribution based on gauge data for the period of 1980 to 2013 at Glenaladale on the Mitchell River. MAF at Glenaladale varies from 123 to 1394 GL with a mean of 724 GL. Mean monthly flow varies from 16 to 138 GL between the months with 78% of the annual flow occurring from June to October.

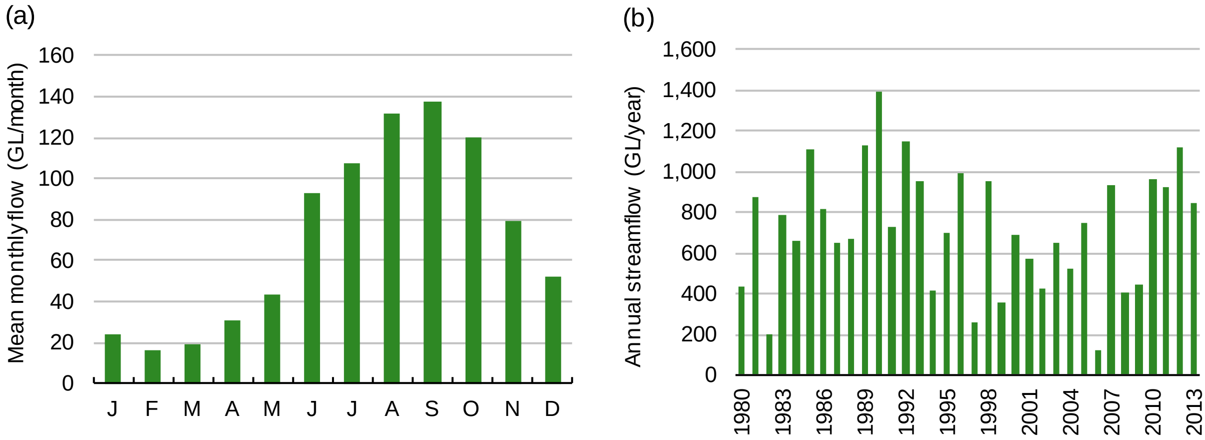

Figure 40 Flow distribution at Glenaladale on the Mitchell River in Mitchell-Thomson River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:224203)

Data: Bioregional Assessment Programme (Dataset 5)

Water in the Snowy River Region is predominantly derived from runoff from the headwater catchments of the Snowy River, located outside the bioregion. The runoff across the river region varies based on location within the river region. The mean annual runoff for a headwater catchment at Bombala is 89 mm and it is 68 mm at a downstream gauge at Jarrahmond on the Snowy River. Streamflow varies between years and months. Figure 41 shows an example of yearly and monthly flow distribution based on observed streamflow data at Sardine Creek on the Brodribb River in the Snowy River Region. MAF between the periods from 1980 to 2013 varies from 27 to 308 GL with a mean of 98 GL. Monthly flow varies from 5 to 20 GL with about 67% flow occurs during June to October.

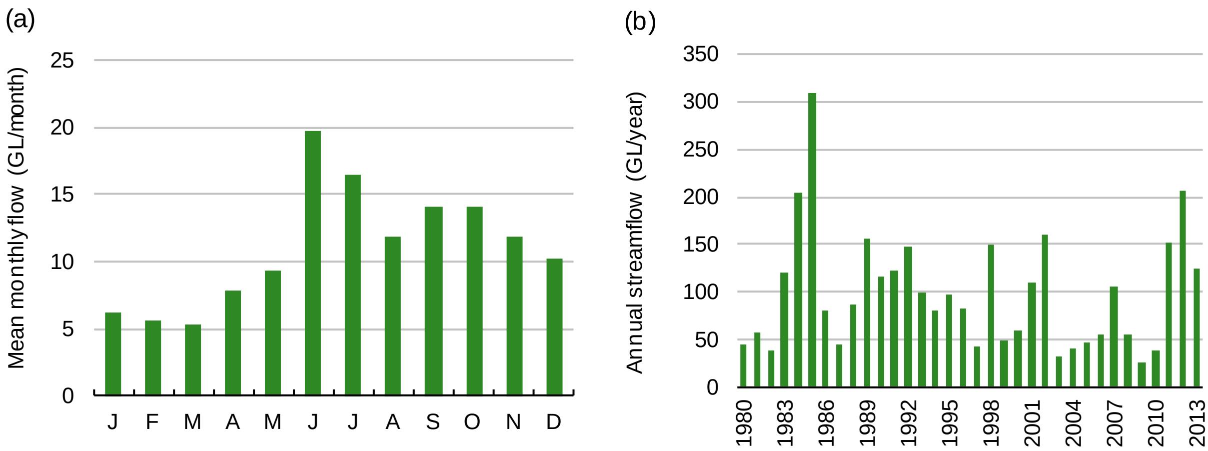

Figure 41 Flow distribution at Sardine Creek on the Brodribb River in Snowy River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:222202)

Data: Bioregional Assessment Programme (Dataset 5)

The source of water in the East Gippsland River Region that is part of Gippsland Basin bioregion originates in the headwaters of the Bemm and Cann rivers. Only the Bemm and Cann rivers of the East Gippsland River Region contribute surface water to the Gippsland Basin bioregion. The annual average runoffs are 131 mm and 168 mm for the Bemm river basin at pump house (GS 221225) and the Cann river basin at Offtake (GS 221224), respectively. All across the river region, streamflow varies between years and months. A typical example of monthly and annual flow distribution is shown in Figure 42. MAF between the periods from 1980 to 2013 varies from 48 to 417 GL with a mean of 160 GL. Monthly flow varies from 6 to 27 GL, 75% of the mean annual flow occurred during June to October.

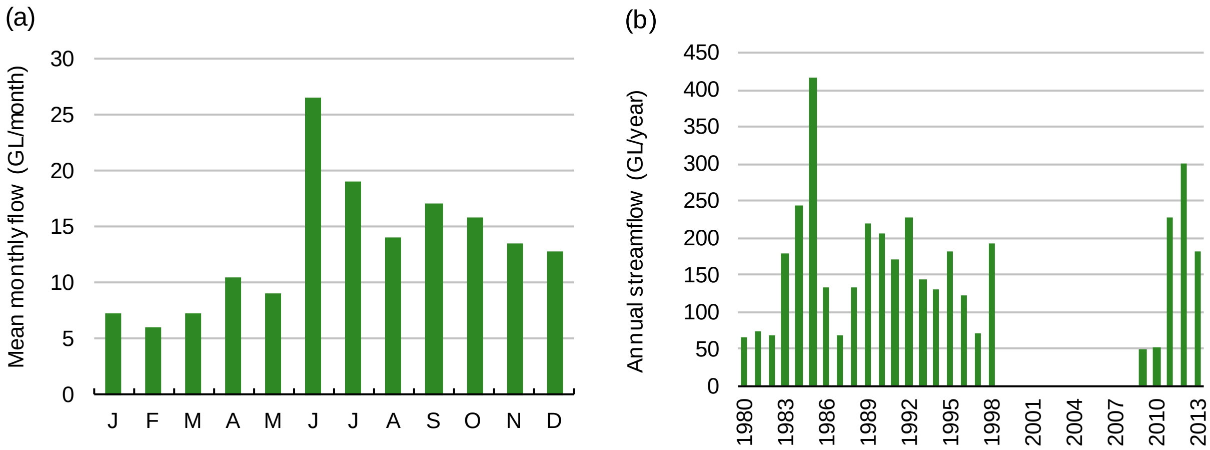

Figure 42 Flow distribution at Princes Highway on the Bemm River in East Gippsland River Region for the Gippsland Basin bioregion, (a) mean monthly and (b) annual (GS:221212)

Data: Bioregional Assessment Programme (Dataset 5)

Information on water availability and entitlements is available for all major watercourses in the Gippsland Basin bioregion. Table 19 shows the annual average volume of surface water availability for consumptive use and water that remains in each river region for the environment. It is based on long-term annual averages of about 50 years of data reported in Department of Environment and Primary Industries (2011). It is important to note that because these are annual average estimates, the volume of use or streamflow in any one year is unlikely to match the annual average. Actual use and streamflow will vary from year to year with climate variability and the historical take-up of entitlements. The estimates in the table reflect an upper limit that could be taken under the entitlements, rather than historical use.

Table 19 Surface water availability and usage for the river regions in the Gippsland Basin bioregion

River Region	Mean annual flow (GL/year)	Bulk entitlements (GL/year)	Licensed diversion (GL/year)	Catchment dam (GL/year)	Unallocated water (GL/year)	Environmental entitlement (GL/year)	Environmental flows (GL/year)
East Gippsland	714.0	0.6	0.6	1.6	16.0	0.0	695.2
Mitchell–Thomson	3131.5	563.9	51.7	44.2	26.1	18.1	2427.5
Snowy	2162.1	1142.0	3.1	2.0	0.0	46.6	968.4
South Gippsland	911.5	9.6	10.5	32.2	38.0	0.0	821.3

Source: Department of Environment and Primary Industries, Victorian Government.
Note: Bulk entitlement includes unban, industrial and irrigation usage

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1.1.6 Surface water – groundwater interactions

Summary

Surface water – groundwater interactions in the Gippsland Basin bioregion follow a pattern of rainfall recharge to outcropping aquifers in the highlands regions to the north of the bioregion (losing streams) and groundwater discharge to connected gaining surface water systems in the lowlands. Surface water – groundwater interactions are shown to be dynamic spatially (from highlands to lowlands) and temporally (seasonally to decades). Further studies and data collection would be needed to elucidate the processes and quantify the amount of surface water – groundwater interactions and the effects of changes in rainfall and groundwater extraction.

1.1.6.1 Overview

Surface water – groundwater interactions in the Gippsland Basin bioregion are summarised into three river region boundaries derived from the Australian Hydrological Geospatial Fabric (Geofabric – v2.1.1) (Bureau of Meteorology, 2013) as used in Section 1.1.5 Figure 30.

- South Gippsland – including waterways in the Tarwin Basin and Alberton Depression
- Mitchell–Thomson Rivers – including waterways in the highlands to the north of the bioregion, Moe Swamp Basin, Latrobe Valley Depression, Lake Wellington Depression and Seaspray Depression
- Snowy River–East Gippsland – including waterways east of Orbost.

Southern Rural Water (2012) generalised the key surface – groundwater interactions in the Gippsland Basin bioregion as:

- Local groundwater flow systems occurring around the basin margins along the flanks of the mountain ranges. Groundwater flow paths are steep and short before the water intercepts the ground surface in depressions and streambeds.
- Intermediate and regional groundwater flow systems occurring in the flatter gradients of the central floodplains and coastal sections of the Gippsland Basin. Shallow groundwater in these regions discharges to the Gippsland Lakes and surrounding wetlands. Deeper groundwater is thought to flow under the lakes and discharge offshore.

Two summary studies have calculated baseflow indices at various surface water gauging stations across the Gippsland Basin bioregion using the US Geological Survey hydrograph separation (HYSEP) (hydrograph separation) methodology, which analyses river gauge hydrographs to determine the likely contributions of baseflow as opposed to surface runoff (Minchin, 2010; Nicol, 2010). These baseflow indices range from 6% (runoff dominated) to 82% (baseflow dependent).

However, the results of different methods to identify gaining and losing behaviour are not universally consistent in the Gippsland Basin (Hofmann, 2011), suggesting that care must be taken when interpreting or using the results of surface water – groundwater interaction studies undertaken to date. For example, Hofmann (2011) identified a discrepancy in results between methods for baseflow analyses among differential surface water gauging stations versus singular river hydrograph analysis for the Avon and Mitchell river systems. The results from these different methods indicated that graphical hydrograph analysis techniques at a single site are biased towards gaining conditions (i.e. there is a component of baseflow if flow exists) while a differential water balance between an upstream and a downstream gauging station can be negative (i.e. losing reaches can be identified).

Hofmann and Cartwright (2013) concluded for the Gippsland Basin bioregion that the aquifer flow system revealed by geochemistry is more complex than could have been realised from groundwater levels alone (aquifers sampled encompassed the Haunted Hill Formation, Boisdale Formation, Baloock Formation, Strzelecki Group, Latrobe Group, Thorpdale Volcanics and Childers Formation). Baseflow to a river is highly variable along a river's flow path (Hofmann, 2011). Furthermore, Hofmann (2011) detailed the importance of short- to medium-term bank storage of the Avon and Mitchell Rivers in the Gippsland Basin bioregion and the implications for distinguishing baseflow separation. Large flood events will recharge river banks, which then return groundwater from the banks without interacting with regional groundwater.

1.1.6.2 South Gippsland

The South Gippsland river region is comprised of relatively small, dynamic and independent river systems flowing from the Strzelecki Ranges in the north to the southern Victorian estuarine and coastal environments (Sinclair Knight Merz, 2012). The river region area is 6677 km^2 and includes the unregulated Tarra, Agnes, Albert/Jack, Franklin, Tarwin and Powlett rivers, and Merriman Creek. Sinclair Knight Merz (2012) identified that rivers in the upper river region have sustained stream flow for the majority of the year while in the mid to lower river region, stream flow is sustained for less than 50% of the time. The modelled streamflow proportion of depletion and lag rate, following groundwater extraction, indicate the rivers of South Gippsland are moderately connected to adjoining aquifers (Sinclair Knight Merz, 2012).

The Cretaceous-aged metasediments of the Strzelecki Group and Paleozoic-aged bedrock outcrop in the north of the river region, forming fractured rock aquifers with local flow paths and localised alluvial valley infill sequences. In the highlands Lower Tertiary volcanics have produced layered aquifers. The Tertiary Latrobe Valley Coal Measures and Boisdale Formation aquifers form regional aquifer flow systems in the lower reaches of the river region (Sinclair Knight Merz, 2012).

The Tarra River has the highest water yield of the river region averaging 42% of total annual flows of all rivers within South Gippsland (Sinclair Knight Merz, 2012). Baseflow at the main Tarra River gauge of Yarram has declined by 75% since the 1950s (Sinclair Knight Merz, 2006). Generalised Additive Model (GAM) analysis of baseflow trends between the late 1960s and the present, combined with analytical calculations, indicates a baseflow decline of about 40% over the critical low-flow months of February and March from about 12 ML/day to 8 ML/day (Evans, 2007). The Tarra River basin has been the focus of several investigations of the occurrence, extent and magnitude of surface water and groundwater interactions at river basin and river sub-basin scales (GHD, 2009). Limitations of data and methods used for these investigations have restricted the quantification of surface water and groundwater interactions (GHD, 2009). Sinclair Knight Merz (2006) note that prior studies show significant reductions in baseflow associated with regionally declining groundwater levels. Sinclair Knight Merz (2006) report that the reduction in baseflow was likely to be mainly caused by a reduction in rainfall over this period, with circumstantial evidence suggesting that the decline in baseflow may also be due to groundwater extraction, to a lesser extent. However, due to data constraints, previous analyses were not conclusive and warranted further data collection (Sinclair Knight Merz, 2006).

In the geological Tarwin Basin and Alberton Depression; Nicol (2010) noted less than 50% baseflow component in streams across the southern aspect of the Strzelecki Ranges. Groundwater in the Tarwin Basin primarily discharges to the Tarwin River system and shallow depressions (Nicol, 2010; Pratt, 1985). A groundwater divide restricts flow in or out of the geological basin, subsequently no long groundwater flow paths contribute to net baseflow discharge in the Tarwin Basin. The Tarwin River gauges record relatively low baseflow indices (less than 50%). Pratt (1985) tentatively calculated a baseflow discharge of 6200 ML/year to the west branch of the Tarwin River.

1.1.6.3 Mitchell–Thomson Rivers

In the highlands the outcropping Strzelecki Group bedrock and minor Quaternary alluvial valley fill are characterised by short, rapid groundwater flow paths that discharge to streams (Nicol, 2010). There is a general trend for high baseflow indices for streams within the highlands where bedrock is outcropping (Nicol, 2010).

In the low-lying areas of the geological Moe Swamp Basin, the watertable is elevated due to artesian discharge from the confined aquifers via vertical leakage (Brumley and Holdgate, 1983). This slow discharge is considered to have a role in the maintenance of the Moe Swamp (Brumley and Holdgate, 1983). Drains constructed within this river region now shed water into the Latrobe River.

Groundwater recharge has been identified from localised surface water leakage to groundwater in areas where the aquifers outcrop or subcrop (Fraser, 1980; Schaeffer, 2008; Walker and Mollica, 1990). For example, Brumley et al. (1981) (via stable isotope studies) identified the local recharge of the Morwell Formation where it outcrops along Wilderness Creek and Ten Mile Creek.

The incised river and creek course in the lower alluvial plains of the Avon River basin creates mostly gaining streams due to a relatively shallow watertable (Sinclair Knight Merz, 2008). During average rainfall conditions (pre-1997) the main stem of the Avon River is a strongly gaining system (Jones et al., 2009). In below average rainfall conditions (post-1997), the Avon River system has a reduced baseflow component, though it is still considered to be a gaining system (Sinclair Knight Merz, 2008).

For the Mitchell–Thomson rivers Geofabric river region boundary, Nicol (2010) noted the modified flow regime for the Thomson and Latrobe rivers and the subsequent difficulty in assessing natural baseflow. High baseflow indices have been calculated for the majority of the length along the Thomson and Latrobe rivers (Nicol, 2010).

Hofmann and Cartwright (2013) used a combination of major ions, stable and radiogenic isotopes to assess inter-aquifer mixing and groundwater flow paths. Study data indicate vertical hydraulic gradients are downwards in the west and upwards in the east towards the Gippsland Lakes, with instances of local artesian discharge. Lake Wellington is likely to be receiving groundwater discharge from the Boisdale Formation (Hofmann and Cartwright, 2013; Schaeffer, 2008). Isotope analysis indicates the ages and flow paths of groundwater are complex, suggesting preferential flow through faults and possible interactions with overlying surface water systems. Likewise, groundwater major ion chemistry is relatively consistent throughout all aquifers, indicating interconnectivity and mixing. Additionally, there are issues in attributing baseflow to discharge of groundwater from specific aquifers (Hofmann and Cartwright, 2013).

Hofmann (2011) undertook single-gauge hydrograph analysis which indicates that under low-flow conditions both the Avon and Mitchell rivers are gaining. However, under flood conditions, differential water balance assessment between two hydrographs showed the Avon River to be gaining (upper and lower river gauge comparisons) while the Mitchell River was losing (upper and lower river gauge comparisons) (Hofmann, 2011).The overall Mitchell River water loss in flood conditions is thought by Hofmann (2011) to be due to overbank flooding and river bank infiltration (i.e. reversal of head gradient). Both rivers have gaining and losing sections and vary between gaining and losing over time (Hofmann, 2011).

GHD (2013) investigated methods for quantifying regional baseflow using a digital baseflow filtering approach ’trained‘ to environmental tracer data – in this case, electrical conductivity (EC). This approach was termed the ‘EC mass balance’ (GHD, 2013). The EC mass balance approach was applied to the Lower Thomson–Macalister and the Lower Mitchell river systems. Due to the strong influence of Thomson Dam releases and irrigation diversions there is difficulty in applying the EC mass balance baseflow estimates to the Thomson–Macalister river system (GHD, 2013).

Minchin (2010) noted that leakage from the Mitchell River is a primary recharge process to the alluvial aquifer within the Wy Yung GMA and possibly in the Orbost GMA.

1.1.6.4 Snowy River – East Gippsland

In this part of Victoria, most rivers are unregulated with the exception of the Snowy River, which has heavily modified flow. Perennial flow boundaries may extend into highland areas, indicating gaining surface water from baseflow for the majority of the length along main watercourses (Minchin, 2010).

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1.1.7 Ecology

Summary

The Gippsland Basin bioregion is located along the eastern slopes of the Great Dividing Range in Victoria and extends east and south to the coast. The Gippsland Basin bioregion is an ecologically diverse area. Natural forest, coastal plains and protracted dune systems are characteristic to the east, while the western area consists of high conservation value natural forest, fertile alluvial floodplains for agriculture and major coal deposits. The Gippsland Basin bioregion has however, been subjected to significant human pressure with 57% of the land area cleared of natural vegetation, predominantly for agricultural purposes.

Eucalyptus open forest and woodlands dominate the 43% of uncleared land in the bioregion and support unique grasslands across the Gippsland Plains. Plantation forestry covers 24% of the bioregion. *Acacia* spp*.*, *Melaleuca* spp. and *Banksia* spp. forest or shrublands are associated with marine and estuarine environments. Approximately 24 flora and 45 fauna species are nationally listed as threatened in the Gippsland Basin bioregion by the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act). Four threatened ecological communities are also listed, three of which are Critically Endangered. In 1981, Wilsons Promontory National Park was recognised as a United Nations Educational, Scientific and Cultural Organisation (UNESCO) biosphere reserve as it maintains a high percentage of diverse native vegetation.

Approximately 8350 wetlands have been classified in the Gippsland Basin bioregion. There are three state Heritage rivers, seven estuaries (including Gippsland Lakes), 15 nationally listed wetlands (*A directory of important wetlands in Australia* (DIWA); Department of the Environment, 2014) and three marine national parks. In 1982, Gippsland Lakes and Corner Inlet were both declared Ramsar wetlands of international importance in recognition of outstanding values, features and diversity of habitats. Marine areas are significant for migratory bird species of which 43 species are listed by the EPBC Act as threatened Migratory species.

Condition varies extending from the Great Dividing Range, across the Gippsland Plains to the coast. Many areas remain pristine in the east. However, an increase in environmental pressure and a decrease in condition occur due to land clearing, agriculture, forestry and other human activities across the Gippsland Plains. Lower river reaches are particularly affected.

1.1.7.1 Ecological systems

The Gippsland Basin bioregion encompasses a variety of landscapes that provide very high diversity in flora, fauna and habitats. Of the geographically distinct Interim Biogeographic Regionalisation of Australia (IBRA) classification, the South East Coastal Plain IBRA bioregion occupies the largest land area within the Gippsland Basin bioregion (Figure 43). The South Eastern Highlands IBRA bioregion extends to the north-east, with the South East Corner IBRA bioregion to the south, incorporating the Strzelecki Ranges. The Furneaux IBRA bioregion, which encompasses

Wilsons Promontory, is the only IBRA bioregion to occur only in the Gippsland Basin bioregion (Figure 43), indicative of the high ecological importance of the area.

The Gippsland Basin bioregion sits within the boundaries of the West and East Gippsland Catchment Management Authorities. However, it excludes much of the mountainous Great Dividing Range area to the north-west. Rather, the Gippsland Basin bioregion boundary encloses the undulating Gippsland Plains, with coastal features to the south and east. Many significant rivers (Latrobe, Thomson, Mitchell, Avon, Macalister, Tambo and Snowy rivers) flow from the Great Dividing Range across the plains to the south and south-east, draining into the Gippsland Lakes and surrounding Bass Strait.

Vegetation along the north-western edge of the Gippsland Basin bioregion primarily consists of native eucalyptus forest or woodland communities, characteristic of those found in the Great Dividing Range, and dominated by moist and dry foothill forest, some lowland forest, heathy woodland and valley grassy forest. The native grassland and eucalyptus which once covered the South East Coastal Plain IBRA bioregion have been heavily cleared with European settlement to develop agricultural areas on rich alluvial soils. Remaining native vegetation include lowland and foothill forests, temperate rainforest, heath and grassy woodlands as well as coastal scrub and grasslands.

The South East Corner IBRA bioregion (Figure 43) remains heavily forested with native vegetation, including extensive heathland, woodlands and forests on the plain, with dry and damp forest in the foothills, extending into tall wet forest in the highlands and tablelands. This region is nationally significant as a biodiversity reserve for temperate zone biodiversity in Australia, as the only area nationally where native vegetation is continuous from alpine environments to the coast (Department of Natural Resources and Environment 1997).

The Strzelecki Ranges (South Eastern Highlands IBRA bioregion) (Figure 43) are occupied by wet forest in elevated areas, with cool temperate rainforest in protected gullies. Drier foothills consist of lowland eucalypt forest, however, substantial clearing has occurred for agricultural purposes. The nationally listed Giant Gippsland Earthworm (*Megascolides australis*) is found in the western Strzelecki Ranges and adjoining alluvial soils to the south and south-west.

Wilsons Promontory National Park (Furneaux IBRA bioregion) (Figure 43) maintains the majority of its diverse native vegetation and, as such, was recognised as a UNESCO biosphere reserve in 1981. It is formed of rugged hills, lowlands, beaches and granite headlands and occupied by coastal scrub; heathland; heathy woodland and dry and moist forest. Significant vegetation communities include warm and cool temperate rainforest, and mangroves.

The floristic diversity across the Gippsland Basin bioregion is evident with 28 major vegetation subgroups identified from the National Vegetation Information System (NVIS) Major Vegetation Subgroups (Version 4.1) (Table 20; Figure 44). The diverse landscape provides habitat for unique fauna including birds, frogs, mammals, reptiles and invertebrates. An overlap of southern cool temperate climate zone, along with eastern warm temperate zone in East Gippsland, results in large numbers of flora and fauna native only to East Gippsland. The Gippsland Basin bioregion also maintains high aquatic diversity with rivers, wetlands, estuaries and marine environments (Figure 43). Coastal aquatic areas provide important feeding grounds for migratory birds and habitat for many and varied bird species. Approximately 8350 wetlands are classified within the bioregion (DEPI, 2014), including two Ramsar-listed wetlands. It is broadly thought within the Bioregional Assessment Programme that flora associated with water bodies and/or in the vicinity of water depth of less than 10 m to groundwater will show some level of water dependence.

Land use includes 15 of 18 classes of the Australian Land Use and Management (ALUM) classification scheme (Table 21). Agricultural industry dominates land use with 36% of the Gippsland Basin bioregion under agricultural production. Of this area, less than 2% is irrigated agriculture, which is largely concentrated in the Macalister Irrigation District (adjacent to the Macalister, Thomson and Avon rivers from Lake Glenmaggie to near Sale) (Department of Sustainability and Environment, 2009). The principal agricultural activity is dryland dairy production and beef or sheep grazing on grazing of modified pastures (33%) (Table 21). Plantation forestry is a further major land use (24%) followed by nature conservation (14%). Urban and residential land use totals 11% of the area with less than 3% of the Gippsland Basin bioregion classified as water. Less than 1% of land use is defined as mining and related to brown coal resource, rock and gravel, which is mostly concentrated around Latrobe Valley (GHD, 2014). Recreation and tourism along the coast are important to regional economy.

1.1.7.1.1 Water dependency

Many species and communities, both flora and fauna, are dependent on alternate sources of water (other than rainfall) to survive. These sources might include surface water from streams and wetlands or groundwater either directly from subsurface aquifers, river baseflow or through springs. Groundwater-dependent ecosystems are defined as ‘natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis so as to maintain their communities of plants and animals, ecosystem processes and ecosystem services’ (Richardson et al. 2011). Collectively, these species and communities reliant on alternate water sources are referred to as ‘water-dependent assets’ in the context of the bioregional assessments.

There are a number of water-dependent species and communities in the Gippsland Basin bioregion (Table 22), however knowledge gaps exist for actual water requirements and what the impacts of hydrological change (both surface water and groundwater) might have on their condition.

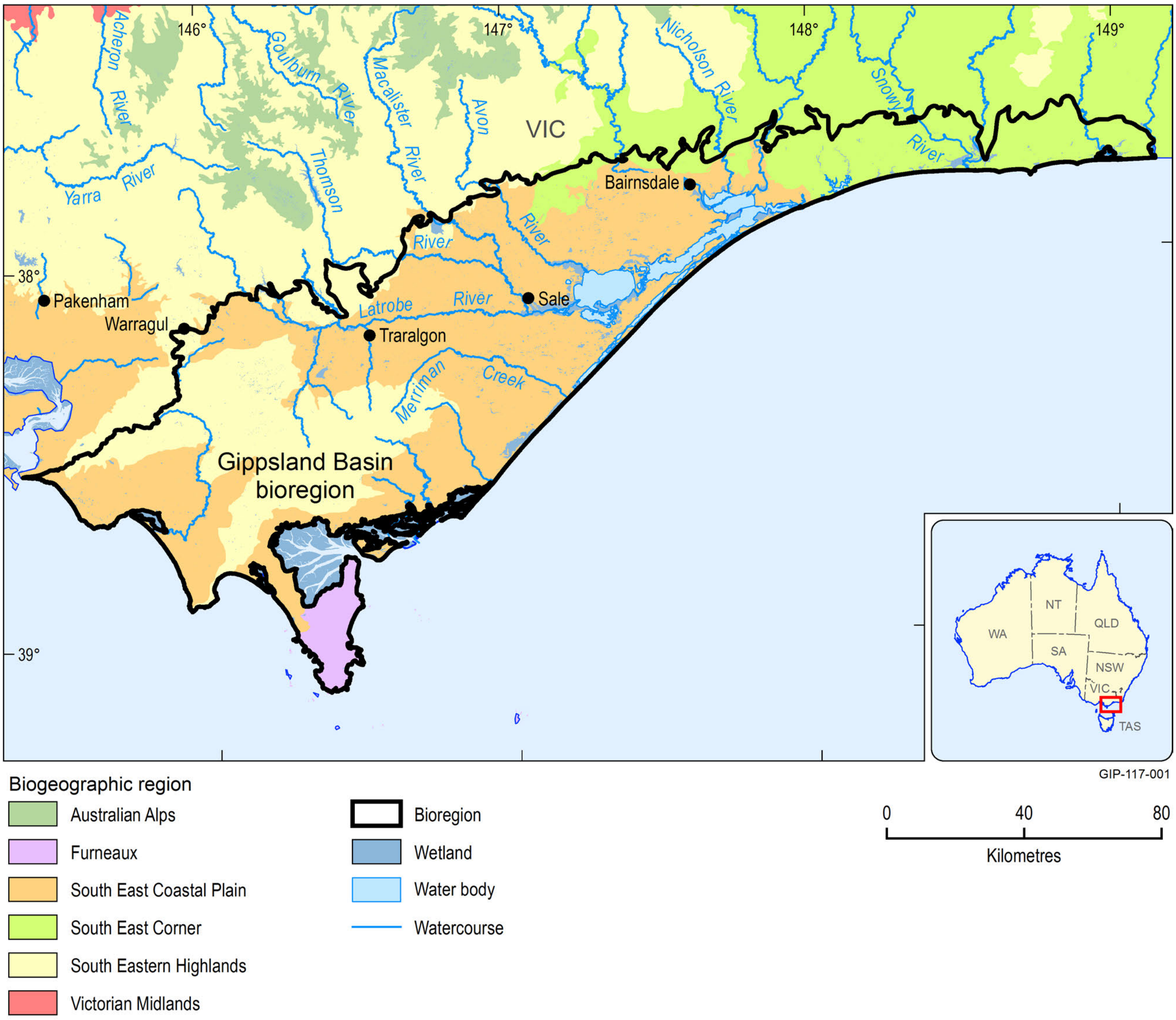

Figure 43 Interim Biogeographic Regionalisation of Australia bioregions (IBRA), wetlands and rivers within the Gippsland Basin bioregion

Data: Department of Sustainability, Environment, Water, Population and Communities (Dataset 1)

Table 20 National Vegetation Information System (NVIS Version 4.1) major vegetation subgroups in the Gippsland Basin bioregion

Typology and punctuation are given as they are used in the legislation

Vegetation subgroups	Area of subgroup (ha)	Area of subgroup as percentage of total (%)	Area of lacustrine or palustrine wetlands (ha)	Area of lacustrine or palustrine wetlands as percentage of total (%)	Area of marine or estuarine wetlands (ha)	Area of marine or estuarine wetlands as percentage of total (%)
Cleared, non-native vegetation, buildings	835,142	57.34%	8204	41.47%	4212	5.53%
Eucalyptus tall open forests and open forests with ferns, herbs, sedges, rushes or wet tussock grasses	175,444	12.05%	553	2.80%	262	0.34%
Eucalyptus open forests with a shrubby understorey	63,360	4.35%	944	4.77%	475	0.62%
Eucalyptus (+/– tall) open forest with a dense broad-leaved and/or tree-fern understorey (wet sclerophyll)	61,259	4.21%	34	0.17%	0	0.00%
Freshwater, dams, lakes, lagoons or aquatic plants	56,783	3.90%	3271	16.53%	47,320	62.12%
Eucalyptus woodlands with a shrubby understorey	51,893	3.56%	1416	7.16%	1892	2.48%
Eucalyptus woodlands with a tussock grass understorey	47,106	3.23%	856	4.33%	3285	4.31%
Eucalyptus open forests with a grassy understorey	31,577	2.17%	210	1.06%	106	0.14%
Heathlands	23,725	1.63%	326	1.65%	196	0.26%
Low closed forest or tall closed shrublands (including Acacia, Melaleuca and Banksia)	21,694	1.49%	352	1.78%	9489	12.46%
Banksia woodlands	19,008	1.31%	457	2.31%	342	0.45%
Melaleuca shrublands and open shrublands	13,395	0.92%	161	0.82%	6	0.01%
Other shrublands	12,947	0.89%	305	1.54%	350	0.46%

Vegetation subgroups	Area of subgroup (ha)	Area of subgroup as percentage of total (%)	Area of lacustrine or palustrine wetlands (ha)	Area of lacustrine or palustrine wetlands as percentage of total (%)	Area of marine or estuarine wetlands (ha)	Area of marine or estuarine wetlands as percentage of total (%)
Eucalyptus woodlands with ferns, herbs, sedges, rushes or wet tussock grassland	10,434	0.72%	885	4.48%	123	0.16%
Saline or brackish sedgelands or grasslands	7541	0.52%	76	0.38%	3614	4.75%
Mixed chenopod, samphire +/– forbs	5682	0.39%	37	0.19%	2492	3.27%
Sedgelands, rushes or reeds	3788	0.26%	951	4.81%	456	0.60%
Temperate tussock grasslands	2789	0.19%	105	0.53%	115	0.15%
Warm temperate rainforest	2720	0.19%	3	0.01%	55	0.07%
Unclassified native vegetation	1825	0.13%	61	0.31%	0	0.00%
Cool temperate rainforest	1653	0.11%	0	0.00%	0	0.00%
Sea, estuaries (includes seagrass)	1584	0.11%	0	0.00%	1100	1.44%
Naturally bare, sand, rock, claypan, mudflat	1309	0.09%	0	0.00%	33	0.04%
Wet tussock grassland with herbs, sedges or rushes, herblands or ferns	1205	0.08%	553	2.79%	0	0.00%
Other Acacia tall open shrublands and shrublands	1033	0.07%	13	0.07%	34	0.05%
Mangroves	792	0.05%	0	0.00%	166	0.22%
Unknown or no data	413	0.03%	9	0.05%	23	0.03%
Other Acacia forests and woodlands	207	0.01%	0	0.00%	10	0.01%
Dry rainforest or vine thickets	69	0.00%	0	0.00%	14	0.02%
Other grasslands	34	0.00%	0	0.00%	0	0.00%
Total	1,456,410	100.00%	19,781	1.36%	76,171	5.23%

Data: Department of the Environment and Water Resources (Dataset 2)

Table 21 Australian Land Use and Management land use classes in the Gippsland Basin bioregion

Typology and punctuation are given as they are used in the legislation

Land use class	Area in bioregion (ha)	Area in region, as percentage of total (%)
Grazing modified pastures	477,401	32.78%
Plantation forestry	343,313	23.57%
Nature conservation	211,084	14.49%
Production forestry	140,183	9.63%
Urban intensive uses	88,703	6.09%
Rural residential and farm infrastructure	70,729	4.86%
Water	35,295	2.42%
Other minimal use	35,227	2.42%
Dryland cropping	27,100	1.86%
Irrigated pastures	18,250	1.25%
Dryland horticulture	4167	0.29%
Irrigated cropping	2548	0.17%
Mining and waste	1584	0.11%
Intensive animal and plant production	448	0.03%
Irrigated horticulture	241	0.02%
Total	**1,456,273**	

Data: ABARES (Dataset 3)

1.1.7.2 Terrestrial species and communities

1.1.7.2.1 Principal vegetation types and distribution patterns

The impact of vegetation clearing in the Gippsland Basin bioregion is evident with 57% of the bioregion covered with non-native vegetation and buildings (Table 20). Of native vegetation identified in the NVIS, 12% of the Gippsland Basin bioregion is covered in eucalyptus tall open forest and open forest with ferns, herbs, sedges, rushes or wet tussock grasses predominately in the east (Figure 44). A large area of open forest is situated in the southern Strzelecki Ranges. The combined eucalyptus open forest categories in Table 20 occupy 23% of the Gippsland Basin bioregion. Collectively, Eucalyptus woodlands occupy a smaller area (8%) but show a high association with palustrine and lacustrine wetlands (16%) compared to eucalyptus open forest (9%);Table 20). *Acacia*, *Melaleuca* and *Banksia* forest or shrublands are associated with marine and estuarine wetlands (12%) as are saline or brackish sedgelands or grasslands (5%).

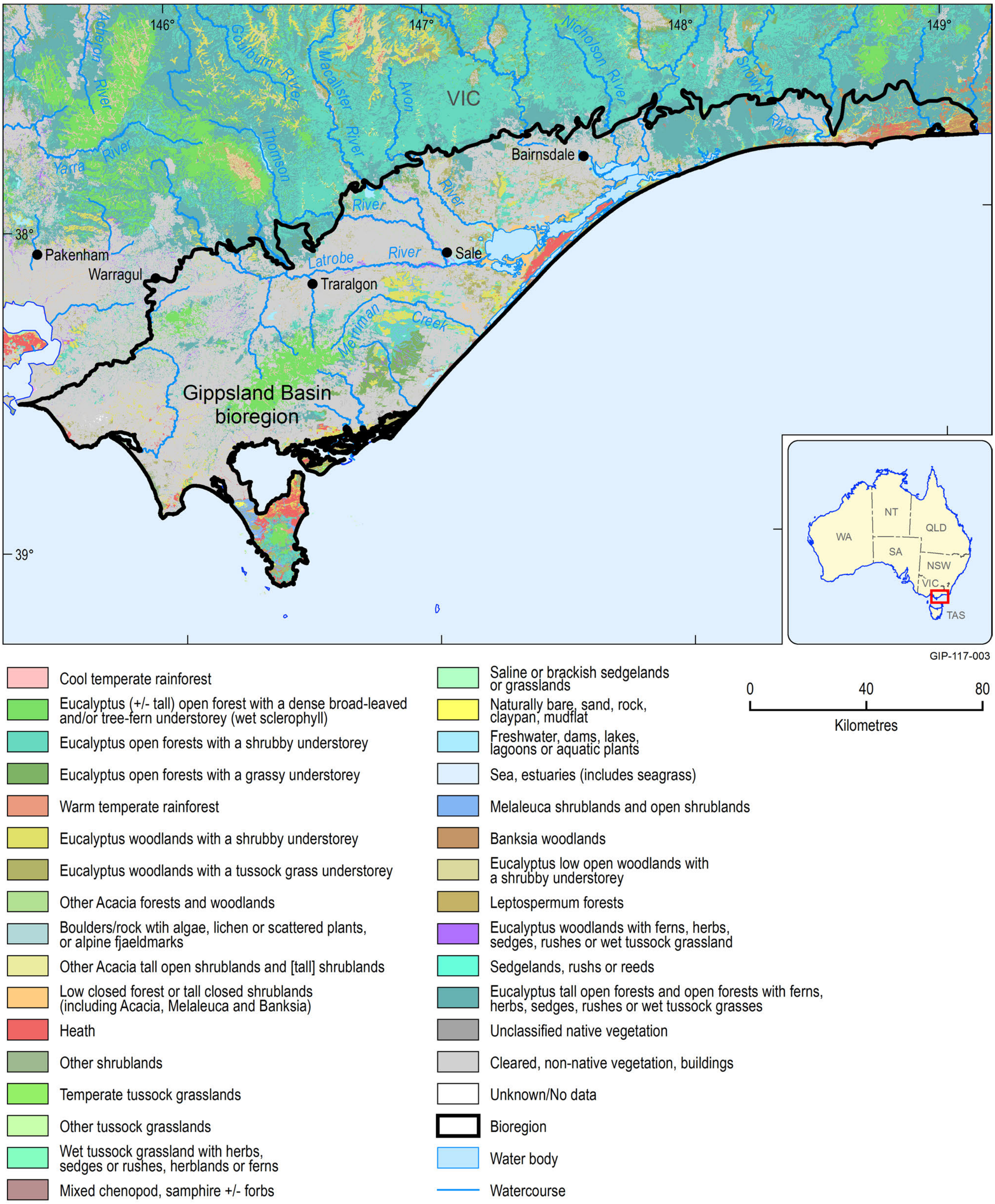

Figure 44 National Vegetation Information System (NVIS) major vegetation subgroups

Data: Department of the Environment and Water Resources (Dataset 2)

1.1.7.2.2 Species and ecological communities of national significance

The EPBC Act lists threatened flora, fauna and ecological communities under a number of classifications. In the Gippsland Basin bioregion the common classifications and their definitions include:

- **Critically Endangered**: species face a high risk in the wild of extinction in the immediate future
- **Endangered**: species face a high risk in the wild of extinction in the near future
- **Vulnerable**: species face a high risk in the wild of extinction in the medium-term future.

Approximately 24 flora species are nationally protected, with six classified as Endangered and 15 as Vulnerable (Table 22).

Within the fauna biodiversity asset group (Table 22), a total of 45 fauna species are listed as threatened including frogs (one Endangered, four Vulnerable), bats (one Vulnerable), fish (two Vulnerable), invertebrates (one Vulnerable), mammals (six Endangered, five Vulnerable), marine birds (two Endangered, six Vulnerable), waders (one Vulnerable), passerine birds (two Endangered), non-passerine birds (one Critically Endangered, three Endangered, two Vulnerable) waders (one Vulnerable) and reptiles (one Endangered, one Vulnerable).

The Orange-bellied Parrot (*Neophema chrysogaster*), endemic to southern Australia, is the only Critically Endangered species thought to occur in the Gippsland Basin bioregion in association with Jack Smith Lake, indicating potential water dependence.

The importance of the natural diversity maintained within Wilsons Promontory National Park is highlighted with designation of the National Park as a UNESCO biosphere reserve in 1981. Diverse vegetation communities exist which include warm temperate and cool temperate rainforest, tall open forests (*Eucalyptus* spp.), woodlands, heathlands, swamp and coastal communities including mangroves (Parks Victoria, 2002). Three threatened fauna species and three flora species occur within Wilsons Promontory National Park (species name identified with [c] in Table 22) and one EPBC Act listed migratory species, Sanderling (*Calidris alba*).

Threatened ecological communities

Ecological communities consist of a naturally occurring group of animals, plants or other biota that interact in a unique habitat. There are 12 EPBC Act listed threatened ecological communities (not shown) in the East and West Gippsland Catchment Management Authorities, however, only four are likely to occur in the Gippsland Basin bioregion (Table 22). Three communities are Critically Endangered including the ecologically significant Gippsland Red Gum (*Eucalyptus tereticornis* subsp. *mediana*) Grassy Woodland and Associated Native Grassland. One community, the Subtropical and Temperate Coastal Saltmarsh, is listed as Vulnerable.

The Gippsland Red Gum Grassy Woodland and Associated Native Grassland community is endemic to the region and nationally important as a temperate grassland and grassy woodland ecosystem. Temperate grassland ecosystems are poorly preserved and conserved nationally, and their decline in Gippsland is largely due to land clearing (DEWHA, 2010). The community provides habitat to other threatened flora and fauna and is known to be rich in wildflowers and other plant species (DEWHA, 2010). The association of this vegetation community with water bodies (Table 20) suggests some level of water dependency.

1.1.7.2.3 Species of regional significance

Victoria's *Flora and Fauna Guarantee Act 1988* (the FFG Act) provides the statutory mechanism for the conservation of flora and fauna that are threatened in the state. In the Gippsland Basin bioregion, 41 flora species are listed as Threatened (FFG Act) of which 16 are listed as Endangered and 11 as Vulnerable (the EPBC Act) (Table 22).

Threatened fauna species total 35 and include four frogs, one bat, two fish, one invertebrate, nine mammals, eight marine birds, two passerine birds, six non-passerine birds, one wader and two reptiles. Many of the FFG Act listed fauna species are also EPBC Act listed (Table 22).

The Victorian Department of Environment, Land, Water and Planning (DELWP) Threatened Species Advisory List is an additional non-statutory state listing of importance to planning processes. Approximately 32 flora species are listed as Endangered and 70 as Vulnerable. There are ten fauna species that are listed as Critically Endangered, 15 are listed as Endangered and 12 listed as Vulnerable.

Threatened ecological communities

State ecological vegetation community mapping (Native Vegetation-Modelled 2005 Ecological Vegetation Classes (EVC)) identifies 629,569 ha of vegetation communities in the Gippsland Basin bioregion of which 139,906 ha (22%) have a Victorian Bioregional Conservation Status of Vulnerable and 100,775 ha (16%) are Endangered (Figure 45). Broad EVC groups that are Endangered include riparian scrubs or swamp scrubs and woodlands (31,000 ha), plains woodlands and forest (including grasslands, 25,000 ha) and damp forests (24,000 ha). Many other Endangered EVC groups exist within the bioregion, but cover much smaller areas. Lowland forest (51,000 ha), plains woodlands and forest (including grasslands, 30,000 ha) are considered Vulnerable. Approximately 12,000 ha of wetland species are also threatened.

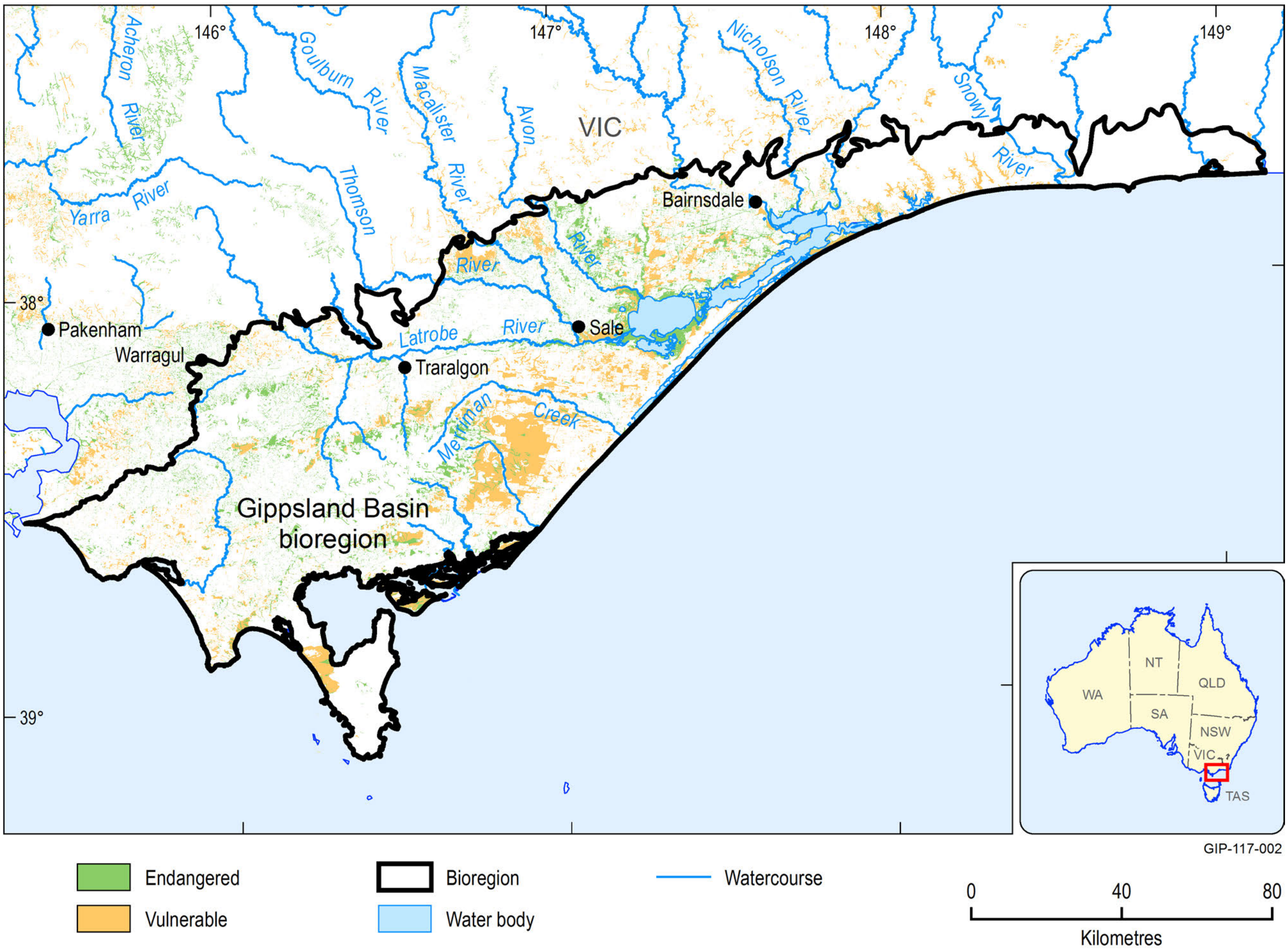

Figure 45 Distribution of ecological vegetation communities with Endangered and Vulnerable conservation status within the Gippsland Basin bioregion

Data: Department of Environment and Primary Industries (Dataset 4)

1.1.7.2.4 Threatening processes

The following potentially threatening processes were collated under the FFG Act. Processes such as alteration to natural flow regimes of rivers and streams, collection of native orchids, degradation of native riparian vegetation along rivers and streams, and fragmentation of habitat are pertinent threats. Introduced plants and animals threaten both terrestrial and aquatic systems through outcompeting and damaging or destroying native biodiversity. In coastal areas, dune degradation resulting from vegetation removal and human impacts threaten biodiversity. In aquatic systems, water quality is threatened by agricultural practices and erosion mechanisms (landslips, gully, sheet rill and river bank erosion) generating sediment and nutrient movement into waterways. In such instances, stream ecology is altered impacting flora and fauna. Grazing or altered hydrology also results in loss of fringing wetland vegetation. Further land clearing poses a major threat to bioregional habitats and biodiversity.

Table 22 Species and ecological communities within the Gippsland Basin bioregion listed as threatened nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act). State-listed threatened species under Victoria's *Flora and Fauna Guarantee Act 1988* (the FFG Act) are indicated with a box

Biodiversity asset group	Scientific name	Common name	Status under the EPBC Act	Status under the FFG Act	Water dependence	Comments on water dependence
Plants						
	Acacia caerulescens	Limestone Blue Wattle	Vulnerable	■	Possible	Wide range of habitats - often grows close to rivers, lakes and roads
	Acacia maidenii	Maiden's Wattle	na	■	Likely	Grows at the outer margin of floodplains
	Acronychia oblongifolia	Yellow-wood	na	■	Possible	Occurs in and on the margins of warm rainforests
	Adiantum diaphanum	Filmy Maidenhair	na	■	Likely	Grows along streams and around waterfalls
	Amphibromus fluitans	River Swamp Wallaby-grass	Vulnerable		Likely	Wetland species
	Boronia galbraithiae	Aniseed Boronia	Vulnerable	■	Likely	Maybe facultative
	Botrychium australe	Austral Moonwort	na	■	Possible	Wide range of habitats – may be facultative near streams
	Caladenia orientalis	Eastern Spider-orchid	Endangered	■	Unlikely	Grows in well-drained soils
	Caladenia peysleyi	Heath Spider-orchid	na	■	Unknown	NA
	Caladenia tessellata[ac]	Thick-lipped Spider-orchid	Vulnerable	na	Unlikely	Grows in well-drained sand/clay loam in heath or grassy woodlands
	Caladenia valida	Robust Spider-orchid	na	■	Unknown	NA
	Cardamine tryssa	Dainty Bitter-cress	na	■	Unknown	NA
	Craspedia canens	Grey Billy-buttons	na	■	Possible	Grows in wet and dry situations May be facultative
	Cryptostylis erecta	Bonnet Orchid	na	■	Likely	Found along creek lines and rhizomes. Need to be moist at all times
	Cryptostylis hunteriana	Leafless Tongue-orchid	Vulnerable	■	Likely	Grows in swampy heaths
	Cullen parvum	Small Scurf-pea	na	■	Possible	Appears to require winter flooding

Biodiversity asset group	Scientific name	Common name	Status under the EPBC Act	Status under the FFG Act	Water dependence	Comments on water dependence
	Cyathea cunninghamii	Slender Tree-fern	na	■	Likely	Grows in deep gullies beside creeks
	Cyathea leichhardtiana	Prickly Tree-fern	na	■	Possible	Occurs on mountain slopes near creeks
	Dianella amoena	Matted Flax-lily	Endangered	■	Possible	Grows in well-drained to seasonally wet soils in lowland grassland, grassy woodland, valley grassy forest and creeklines
	Diuris punctata var. *punctata*	Purple Diuris	na	■	Possible	May be facultative – occurs in association with red gum and swamp gum
	Dodonaea procumbens	Trailing Hop-bush	Vulnerable	na	Possible	Grows in low-lying, often winter wet locations
	Eucalyptus strzeleckii	Strzelecki Gum	Vulnerable	■	Likely	Seasonal waterlogging
	Grevillea celata	Colquhoun Grevillea	Vulnerable	■	Unlikely	Occurs in dry schlerophyll woodland and heathy open forest
	Hakea macraeana	Willow Needlewood	na	■	Possible	Found in understorey of wet or dry sclerophyll forest, drought resistant
	Isopogon prostratus	Prostrate Cone-bush	na	■	Unlikely	Occurs in heath on plateaux and ridges or dry open eucalypt woodland
	Lachnagrostis punicea subsp. *filifolia*	Purple Blown-grass	na	■	Likely	Occurs in wet marshes and slightly saline swamps and depressions
	Lindsaea trichomanoides	Oval Wedge-fern	na	■	Unknown	Found on dry sites in lowland to montane forest/shrubland
	Livistona australis	Cabbage Fan-palm	na	■	Likely	Often in swampy sites
	Nematolepis frondosa	Leafy Nematolepis	Vulnerable	■	Unlikely	Varied habitats including rocky outcrops and tall open forest
	Pomaderris vacciniifolia	Round-leaf Pomaderris	na	■	Likely	Found along creek lines

Biodiversity asset group	Scientific name	Common name	Status under the EPBC Act	Status under the FFG Act	Water dependence	Comments on water dependence
	Prasophyllum correctum	Gaping Leek-orchid	Endangered	■	Unlikely	Grows in freely draining soils
	Prasophyllum frenchii[c]	Maroon Leek-orchid	Endangered	■	Likely	Occurs in swampland
	Prasophyllum spicatum	Dense Leek-orchid	Vulnerable	na	Likely	Seasonal waterlogging
	Prostanthera galbraithiae	Wellington Mint-bush	Vulnerable	■	Unlikely	NA
	Pseudoraphis paradoxa	Slender Mud-grass	na	■	Likely	Grows in and around pools and watercourses
	Pterostylis baptistii	King Greenhood	na	■	Likely	Grows in moist to wet soils
	Pterostylis chlorogramma	Green-striped Greenhood	Vulnerable	■	Possible	Occurs in moist well-drained soils
	Pterostylis cucullata[ac]	Leafy Greenhood	Vulnerable	■	Likely	Inland populations occur on river banks or alluvial floodplains. Coastal populations grow in seasonally damp, well-drained sandy loams
	Pterostylis lustra	Small Sickle Greenhood	na	■	Likely	Restricted to swampy areas
	Pterostylis tenuissima	Swamp Greenhood	Vulnerable	na	Likely	Based on naming
	Rulingia prostrata[b]	Dwarf Kerrawang	Endangered	■	Likely	Associated with wetland margins
	Sambucus australasica	Yellow Elderberry	na	■	Possible	Grows on the edges of rainforests and widespread in coastal districts
	Symplocus thwaitesii	Buff Hazelwood	na	■	Likely	Grows alongside Snowy River
	Thelymitra epipactoides[b]	Metallic Sun-orchid	Endangered	■	Unlikely	NA
	Thelymitra incurva	Swamp Sun-orchid	na	■	Possible	Grows in heathlands and heathy woodlands mostly around the edges of grasstree plains
	Xerochrysum palustre[b]	Swamp Everlasting	Vulnerable	■	Likely	Grows in wetlands, seen growing in water 1 m deep

Biodiversity asset group	Scientific name	Common name	Status under the EPBC Act	Status under the FFG Act	Water dependence	Comments on water dependence
Frogs						
	Heleioporus australiacus	Giant Burrowing Frog	Vulnerable	■	Likely	NA
	Litoria aurea[b]	Green and Golden Bell Frog	Vulnerable	na	Likely	NA
	Litoria littlejohni	Large Brown Tree Frog	Vulnerable	■	Likely	NA
	Litoria raniformis[ab]	Southern Bell Frog	Vulnerable	■	Likely	NA
	Litoria spenceri	Spotted Tree Frog	Endangered	■	Likely	NA
Bats						
	Pteropus poliocephalus	Grey-headed Flying-fox	Vulnerable	■	Likely	NA
Fish						
	Galaxiella pusilla	Dwarf Galaxias	Vulnerable	■	Likely	NA
	Prototroctes maraena[a]	Australian Grayling	Vulnerable	■	Likely	NA
Invertebrates						
	Megascolides australis	Giant Gippsland Earthworm	Vulnerable	■	Likely	NA
Mammals						
	Arctocephalus tropicalis	Sub-antarctic Fur-Seal	Vulnerable	na	Likely	NA
	Dasyurus maculatus[c]	Spot-tailed Quoll	Endangered	■	Likely	NA
	Eubalaena australis[a]	Southern Right Whale	Endangered	■	Likely	NA
	Gymnobelideus leadbeateri	Leadbeater’s Possum	Endangered	■	Likely	NA
	Isoodon obesulus obesulus	Southern Brown Bandicoot (Eastern)	Endangered	■	Likely	NA
	Megaptera novaeangliae	Humpback Whale	Vulnerable	■	Likely	NA
	Mirounga leonina	Southern Elephant Seal	Vulnerable	na	Likely	NA
	Potorous longipes	Long-footed Potoroo	Endangered	■	Likely	NA
	Potorous tridactylus tridactylus[c]	Long-nosed Potoroo	Vulnerable	■	Likely	NA

Biodiversity asset group	Scientific name	Common name	Status under the EPBC Act	Status under the FFG Act	Water dependence	Comments on water dependence
	Pseudomys fumeus	Smoky Mouse	Endangered	■	Likely	NA
	Pseudomys novaehollandiae[c]	New Holland Mouse	Vulnerable	na	Likely	NA
Marine birds						
	Diomedea exulans (sensu lato)	Wandering Albatross	Vulnerable	■	Likely	NA
	Halobaena caerulea	Blue Petrel	Vulnerable	na	Likely	NA
	Macronectes giganteus	Southern Giant-Petrel	Endangered	■	Likely	NA
	Macronectes halli	Northern Giant-Petrel	Vulnerable	■	Likely	NA
	Phoebetria fusca	Sooty Albatross	na	■	Likely	NA
	Thalassarche bulleri	Buller's Albatross	Vulnerable	■	Likely	NA
	Thalassarche carteri	Indian Yellow-nosed Albatross	na	■	Likely	NA
	Thalassarche cauta cauta[a]	Shy Albatross	Vulnerable	■	Likely	NA
	Thalassarche chrysostoma	Grey-headed Albatross	Endangered	■	Likely	NA
	Thalassarche melanophris	Black-browed Albatross	Vulnerable	na	Likely	NA
Passerine birds						
	Anthochaera phrygia	Regent Honeyeater	Endangered	■	Likely	NA
	Dasyornis brachypterus	Eastern Bristlebird	Endangered	■	Likely	NA
Non-passerine birds						
	Botaurus poiciloptilus	Australasian Bittern	Endangered	■	Likely	Nests in swamps
	Calyptorhynchus banksii graptogyne	Red-tailed Black-Cockatoo (south-eastern)	Endangered	■	Likely	NA
	Lathamus discolor[a]	Swift Parrot	Endangered	■	Likely	NA
	Neophema chrysogaster[a]	Orange-bellied Parrot	Critically Endangered	■	Likely	NA

Biodiversity asset group	Scientific name	Common name	Status under the EPBC Act	Status under the FFG Act	Water dependence	Comments on water dependence
	Polytelis swainsonii	Superb Parrot	Vulnerable	■	Likely	NA
	Rostratula australis	Australian Painted Snipe	Vulnerable	■	Likely	NA
Waders						
	Sternula nereis nereis	Australian Fairy Tern	Vulnerable	■	Likely	NA
Reptiles						
	Dermochelys coriacea[a]	Leathery Turtle	Endangered	■	Likely	NA
	Eretmochelys imbricata	Hawksbill Turtle	Vulnerable	na	Likely	NA
Ecological communities						
	Eucalyptus tereticornis subsp. *mediana*	Gippsland Red Gum (*Eucalyptus tereticornis subsp. mediana*) Grassy Woodland and Associated Native Grassland	Critically Endangered	na	Likely	Some location near water bodies
		Littoral Rainforest and Coastal Vine Thickets of Eastern Australia	Critically Endangered	na	Likely	NA
		Seasonal Herbaceous Wetlands (Freshwater) of the Temperate Lowland Plains	Critically Endangered	na	Likely	Wetland environment
		Subtropical and Temperate Coastal Saltmarsh	Vulnerable	na	Likely	Some groundwater connection

Data: Department of Environment and Primary Industries (Dataset 5)

na – Not applicable as species is not listed
NA – Data related to water dependence are not available
[a] – Species occurs at Corner Inlet Ramsar site
[b] – Species occurs at the Gippsland Lakes Ramsar site
[c] – Species occurs at Wilsons Promontory National Park

1.1.7.3 Aquatic species and communities

1.1.7.3.1 Classification of aquatic habitats

Seven estuaries and 15 wetlands are nationally protected as listed in DIWA (Department of the Environment, 2014; Table 23). Of these, the Gippsland Lakes (including Lake King wetlands, Lake Victoria wetlands and Lake Wellington wetlands) and Corner Inlet are internationally listed on the Ramsar List of Wetlands of International Importance.

Some 8349 wetlands occupying 152,631 ha (Table 24) have been identified and mapped within the Gippsland Basin bioregion by the DELWP. A total of 426 wetlands are classified as estuarine (47% of wetland area), 5344 as lacustrine (6%), three as marine (40%), and 2068 as palustrine (7%). A further 508 are classified as lacustrine or palustrine (<1%). Further wetland descriptions are given in Table 24.

Close to 9000 km of rivers, creeks, streams flow through the Gippsland Basin bioregion of which 142 rivers are ephemeral and 32 are perennial. Only 18 rivers in the Gippsland Basin bioregion are listed under the regional Heritage Rivers Act 1992, including the Bemm, Snowy and Thomson perennial rivers, as rivers requiring protection to reserve valuable features (referred to as Heritage rivers). Detailed stream condition in East and West Gippsland Catchment Management Authorities, determined between 2004 and 2010 (DEPI, 2010), provides baseline stream condition information. In general, the lower reaches on the Mitchell and Snowy rivers are in poor health in East Gippsland while the majority of rivers in West Gippsland are in moderate to poor health across the Gippsland Plains. The Latrobe River, which flows to Lake Wellington, is classed as poor and very poor along its reaches across the plains (DEPI, 2010).

Table 23 Nationally important wetlands in the Gippsland Basin bioregion listed in *A Directory of Important Wetlands in Australia* (Department of the Environment, 2014c)

Wetland name	Classification
Anderson Inlet	Estuary
Bald Hills State Wildlife Reserve	Wetland
Bemm, Goolengook, Arte and Errinundra rivers	Wetland
Billabong Reserve	Wetland
Bosses/Nebbor Swamp	Wetland
Corner Inlet	Estuary
Deep Water Morass	Wetland
Ewings Marsh (Morass)	Wetland
Jack Smith Lake State Game Reserve	Wetland
Lake Bunga	Wetland
Lake King Wetlands	Estuary [a]
Lake Tyers	Wetland
Lake Victoria Wetlands	Estuary [a]
Lake Wellington Wetlands	Estuary[a]

Wetland name	Classification
Lindenow Wildlife Sanctuary	Wetland
Lower Snowy River Wetlands System	Wetland
Macleod Morass	Wetland
Powlett River Mouth	Estuary
Russells Swamp	Wetland
Shallow Inlet Marine & Coastal Park	Wetland
Snowy River	Estuary
Sydenham Inlet Wetlands	Estuary
Tambo River (Lower Reaches) East Swamps	Wetland
Tamboon Inlet Wetlands	Estuary

Data: Department of the Environment, (Dataset 6)
[a] – Gippsland Lakes estuary

Table 24 Area of wetlands in the Gippsland Basin bioregion under four classes, incorporating wetland description

Department of Environment, Land, Water and Planning wetland classification	Wetland description	Number of wetlands	Area (ha)
Estuarine			
	Freshwater meadow	4	143
	Shallow freshwater marsh	7	334
	Deep freshwater marsh	39	12,408
	Permanent open freshwater	1	14,923
	Semi-permanent saline	254	16,922
	Permanent saline	116	26,749
	Unclassified	6	363
Total		**426**	**71,841**
Lacustrine			
	Freshwater meadow	1	3
	Sewage oxidation basin	33	382
	Shallow freshwater marsh	80	467
	Deep freshwater marsh	121	1365
	Permanent open freshwater	5084	6476
	Semi-permanent saline	9	33
	Permanent saline	3	17
	Unclassified	13	96
Total		**5344**	**8838**

Department of Environment, Land, Water and Planning wetland classification	Wetland description	Number of wetlands	Area (ha)
Marine			
	Semi-permanent saline	1	7559
	Permanent saline	2	53,178
Total		**3***	**60,737**
Palustrine			
	Flooded river flats	1	2
	Freshwater meadow	549	1272
	Shallow freshwater marsh	764	2896
	Deep freshwater marsh	620	4811
	Semi-permanent saline	47	917
	Unclassified	87	1038
Total		2068	10,935
Palustrine or lacustrine			
	Shallow freshwater marsh	344	139
	Deep freshwater marsh	158	123
	Unclassified	6	17
Total		**508**	**279**
Grand Total		**426**	**152,631**

Data: Department of Environment and Primary Industries (Dataset 7)

1.1.7.3.2 Ramsar wetlands

There are two Ramsar-listed wetland complexes within the Gippsland Basin bioregion:

- Gippsland Lakes (60,015 ha)
- Corner Inlet (67,186 ha).

These wetlands provide important habitat to migratory birds, with 43 listed as threatened in the EPBC Act migratory species for the Gippsland Lakes and 17 for Corner Inlet (Table 25).

The Gippsland Lakes

The Gippsland Lakes is made up of a group of coastal lagoons and marshes that are separated from the sea by sand dunes and Ninety Mile Beach. Within the Gippsland Lakes, 11 Ramsar wetland types occur and include:

- marine subtidal aquatic beds
- sand, shingle or pebble shores
- estuarine waters

- intertidal marshes
- coastal brackish or saline lagoons
- permanent inland deltas
- permanent river, streams or creeks
- permanent saline, brackish or alkaline marshes and pools
- permanent freshwater marshes and pools
- freshwater tree-dominated wetlands
- wastewater treatment areas.

These provide a wide range of habitats including submerged and emergent macrophytes (e.g. seagrass beds), plankton-dominated open water and fringing wetland (fresh, brackish and hypersaline) vegetation that support nationally and internationally threatened wetland species, waterbird breeding, and fish spawning.

The Gippsland Lakes support 86 waterbird species (BMT WBM, 2011b), many of which are listed under the Japan-Australia *Migratory Birds Agreement* (JAMBA) *1986*, China-Australia *Migratory Birds Agreement* (CAMBA) *1974* and/or the Republic of Korea-Australia *Migratory Birds Agreement* (ROKAMBA) *2007* and are EPBC Act listed as threatened Migratory species (Table 25). The Gippsland Lakes were reported to regularly support 40,000 to 50,000 waterbirds during the 1990s (DSE, 2003). More recent data suggest that they regularly support significantly lower populations – approximately 20,000 waterbirds (BMT WBM, 2011b). Waterbirds utilising freshwater habitats have experienced the most decline. Deep freshwater marshes, salt marsh and shallow permanent saline wetland habitats sustained the highest usage rates by waterbirds in the Gippsland Lakes (Corrick and Norman, 1980).

The Gippsland Lakes Ramsar site provides habitat for two nationally threatened frog species (Table 22), which depend on the presence of permanent, still-to-low flowing freshwater bodies, with aquatic and fringing vegetation. The persistence of these frog populations is mostly dependent on the maintenance of:

- water quality (low nutrients and salinity, adequate dissolved oxygen)
- freshwater inundation (natural freshening patterns that prevent rises in salinity)
- vegetation (extent and condition).

Three nationally threatened wetland-associated flora species occur within the Gippsland Lakes Ramsar site (Table 22). Water regimes that support these species are unknown (BMT WBM, 2011b), however it is likely at least two of the species are water dependent (Table 22).

Many fish species use the marine subtidal aquatic beds in the Gippsland Lakes as a nursery area (BMT WBM, 2011b). There is little known about aquatic invertebrates in the Gippsland Lakes, but they are assumed to perform a number of services such as the basis of food chains, nutrient cycling, breakdown of detritus, habitat for other species, population regulation of other organisms, and maintenance of water quality (BMT WBM, 2011b).

Ecological processes (BMT WBM, 2011b) considered having the strongest influence on the ecological character of the Gippsland Lakes include:

- riverine inflows of freshwater
- groundwater inflows
- marine inflows.

These processes control the variable salinity regime across the Gippsland Lakes and have shaped the ecological patterns and processes. Threats include altered hydrology, invasive species and water pollution (nutrients and sediments).

Corner Inlet

Corner Inlet is a marine embayment that contains tidal channels, sandy barrier islands and drainages from freshwater rivers, creeks and wetlands.

The following Victorian *Ministry for Conservation 1980* wetland types occur at Corner Inlet (BMT WBM, 2011a):

- permanent shallow marine waters (typically less than 6 m at low tide)
- marine subtidal aquatic beds
- intertidal mud, sand or salt flats
- intertidal marshes
- intertidal forested wetlands.

In addition, the following Ramsar wetland types also occur at Corner Inlet:

- rocky marine shores
- sand, shingle or pebble shores
- estuarine waters
- coastal freshwater lagoons
- seasonal rivers/streams/creeks
- permanent freshwater marshes/pools
- seasonal/intermittent freshwater marshes/pools on inorganic soils
- shrub-dominated wetlands
- freshwater, tree-dominated wetlands.

Unconfirmed Ramsar wetland types that may also occur at Corner Inlet include:

- non-forested peatlands
- forested peatlands
- ponds, including farm ponds, stock ponds and small tanks
- canals and drainage channels.

Corner Inlet provides a diverse range of marine, estuarine and freshwater wetland habitats (including the largest seagrass beds (*Posidonia australis*) in Victoria) that support nationally threatened species, bird breeding and fish spawning. Corner Inlet provides habitat for one Critically Endangered and one Endangered bird (Table 22) and 43 Migratory species listed under the JAMBA, CAMBA and/or ROKAMBA (Table 25). The tidal flats and fringing wetland habitats are used by shorebirds for roosting, breeding and feeding. Corner Inlet regularly supports more than 20,000 shorebirds and, at times, more than 40,000. It is also used as a refuge by large aggregations of post-breeding waterbirds when environmental conditions are unfavourable (BMT WBM, 2011a).

Tidal flats, along with the deeper waters, provide habitat for benthic invertebrates. Three of more than 390 marine invertebrates recorded at Corner Inlet appear to be unique to the site and were recommended for listing under the FFG Act as Vulnerable species (BMT WBM, 2011a).

Corner Inlet provides habitat for one nationally threatened frog species (Table 22) which requires permanent or seasonal freshwater flooding and still or slow moving water for breeding to occur and aquatic vegetation for feeding and shelter (EPBC, 2009).

The marine, estuarine and freshwater habitats within Corner Inlet are used by a wide range of fish species (some of commercial interest) for a variety of purposes (including nursery areas, spawning, feeding, shelter, migratory pathway). Three nationally threatened (EPBC Act) Marine species have also been recorded within the Corner Inlet Ramsar site (BMT WBM, 2011a; Table 22).

Corner Inlet also provides food, nesting and nursery areas for many other animals including a variety of reptiles, amphibians, mammals and birds. Approximately 390 species of native flora and 160 species of native terrestrial fauna have been reported at Corner Inlet, as well as a wide variety of marine mammals. Two nationallyVulnerable orchid species occur within the Corner Inlet but these are not considered water dependent (BMT WBM, 2011a; Table 22).

The key threats to the character of Corner Inlet include altered hydrology, climate change, oil spill or marine incident, water pollution (sediment and nutrients), habitat loss due to future development (infrastructure, urban, natural resource), acid sulfate soils, invasive species (flora and fauna) and recreational activities (Department of Sustainability, Environment, Water, Population and Communities, 2011).

Table 25 Migratory shorebirds within Corner Inlet Ramsar site that are listed as EPBC Act Migratory species. Many species are also listed under bilateral agreements as indicated with a box

Migratory birds scientific names	Common name	China-Australia *Migratory Birds Agreement 1974*	Japan-Australia *Migratory Birds Agreement 1986*	Republic of Korea-Australia *Migratory Birds Agreement 2006*
Actitis hypoleucos	Common Sandpiper	■	■	■X
Apus pacificusa	Fork-tailed Swift			
Ardea ibisa	Cattle Egret	■X	■X	
Ardea modesta	Eastern Great Egret	■X	■X	
Ardenna tenuirostris	Short-tailed Shearwater		■X	■X

Migratory birds scientific names	Common name	China-Australia *Migratory Birds Agreement* 1974	Japan-Australia *Migratory Birds Agreement* 1986	Republic of Korea-Australia *Migratory Birds Agreement* 2006
Arenaria interpres	Ruddy Turnstone	■X	■X	■X
Calidris acuminataa	Sharp-tailed Sandpiper	■X	■X	■X
Calidris albaa	Sanderling	■X	■X	■X
Calidris canutusa	Red Knot	■X	■X	■X
Calidris ferrugineaa	Curlew Sandpiper	■X	■X	■X
Calidris melanotos	Pectoral Sandpiper		■X	■X
Calidris ruficollisa	Red-necked Stint	■X	■X	■X
Calidris tenuirostris	Great Knot	■X	■X	■X
Charadrius leschenaultii	Greater Sand Plover	■X	■X	■X
Charadrius mongolus	Lesser Sand Plover	■X	■X	■X
Chlidonias leucopterusa	White-winged Black Tern	■X	■X	■X
Diomedea exulans	Wandering Albatross			
Glareola maldivarum	Oriental Pratincole	■X	■X	■X
Gallinago hardwickiia	Latham's Snipe	■X	■X	■X
*Haliaeetus leucogaster**	White-bellied Sea-Eagle			
Heteroscelus brevipes	Grey-tailed Tattler	■X	■X	■X
Hirundapus caudacutusa	White-throated Needletail			
Hydroprogne caspia	Caspian Tern	■X	■X	
Limosa lapponica	Bar-tailed Godwit	■X	■X	■X
Limosa limosa	Black-tailed Godwit	■X	■X	■X
Macronectes giganteusa	Southern Giant-Petrel			
Merops ornatusa	Rainbow Bee-eater			
Monarcha melanopsisa	Black-faced Monarch			
Myiagra cyanoleucaa	Satin Flycatcher			
Numenius madagascariensis	Eastern Curlew	■X	■X	■X
Numenius phaeopus	Whimbrel	■X	■X	■X
Pluvialis fulva	Pacific Golden Plover	■X	■X	■X
Pluvialis squatarola	Grey Plover	■X	■X	■X
Rhipidura rufifronsa	Rufous Fantail			
Sterna hirundo	Common Tern	■X	■X	■X
Sternula albifronsa	Little Tern	■X	■X	■X
Sterna bengalensis	Lesser Crested Tern	■X		
Thalassarche chrysostoma	Grey-headed Albatross			
Thinornis rubricollisa	Hooded Plover			

Migratory birds scientific names	Common name	China-Australia *Migratory Birds Agreement 1974*	Japan-Australia *Migratory Birds Agreement 1986*	Republic of Korea-Australia *Migratory Birds Agreement 2006*
Tringa glareola	Wood Sandpiper	■X	■X	■X
Tringa nebularia	Common Greenshank	■X	■X	■X
Tringa stagnatilis	Marsh Sandpiper	■X	■X	■X
Xenus cinereus	Terek Sandpiper	■X	■X	■X

[a] = migratory birds also present in the Gippsland Lakes Ramsar site.
Data: BMT WBM (2011a), BMT WBM (2011b)
Migratory shorebirds in Gippsland Lakes are identified with an asterisk. All species are EPBC Act Migratory listed species

1.1.7.3.3 Marine national parks

Three marine national parks are designated beyond the coastal extent of the bioregion boundary and include Ninety Mile Beach Marine National Park, Wilsons Promontory Marine National Park and Corner Inlet Marine National Park. The condition of marine areas is highly dependent on terrestrial processes and quality of water delivered to the ocean.

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