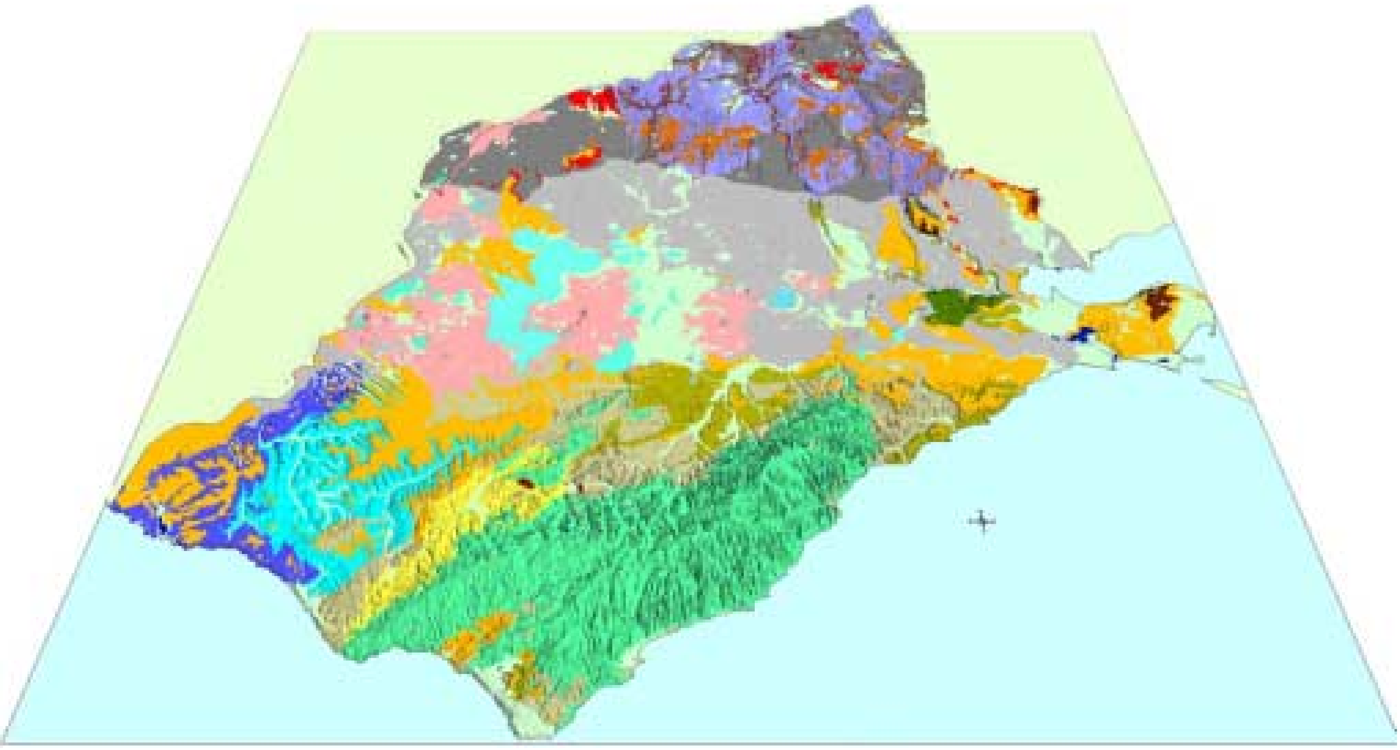
Corangamite
Catchment Management Authority

Groundwater Flow Systems



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Report No. CCMA 02/02

Wednesday 22nd May 2002

Summary

Seventeen groundwater flow systems have been delineated in the Corangamite CMA region based on the model put forward by the National Land and Water Resources Audit. Of these, nine are predominately local groundwater flow systems, four are predominately intermediate, and four are predominately regional flow systems. Consensus on the flow systems was an outcome of a three-day workshop held in Colac in November 2001, and subsequent discussions with regional experts.

Groundwater flow systems are intended to characterise similar landscapes in which similar groundwater processes contribute to similar salinity issues, and where similar salinity management options apply. They comply with a national salinity evaluation framework being developed under the National Action Plan for salinity and water quality to characterise catchments in terms of their response to salinity management options.

The primary purpose of this report is to provide input to projects currently underway as part of the National Action Plan and other programs, including (but not limited to):

_ Renewal of the CCMA Regional Catchment Strategy

_ Second Generation CCMA Salinity Action Plan

_ CCMA Sub-catchment Salinity Risk Prioritisation

_ CCMA Groundwater Monitoring and Research Database

_ CCMA Groundwater Monitoring Guidelines and Review

_ South West Water and Land-use Change Project

While groundwater flow systems provide a useful tool in the understanding of salinity processes, confidence in management options for the protection of different classes of assets (agricultural land, water quality, biodiversity, infrastructure and cultural heritage) requires confidence in the conceptual model of how the groundwater and salinity processes operate. To date there has been very little scientific validation of the flow systems or salinity process models in the Corangamite CMA region.

Recommendations are made for the continuous improvement of data and regular revision of the groundwater flow systems so that the annual expenditure on salinity management can be optimised.

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Disclaimer

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1.0 Introduction

The National Land and Water Resources Audit (NLWRA, 2001) identified the Corangamite Catchment Management Authority (CCMA) region as a high-risk salinity area. As a result, the CCMA (along with the neighbouring Glenelg Hopkins CMA) has been designated one of the priority regions in the National Action Plan for salinity and water quality (NAP). The goal of the NAP is to motivate and enable regional communities to use coordinated and targeted action to:

- Prevent, stabilise and reverse trends in dryland salinity affecting the sustainability of production, the conservation of biological diversity and the viability of our infrastructure.
- Improve water quality and secure reliable allocations for human uses, industry and the environment.

This report details a preliminary assessment of the Groundwater Flow Systems (GFS) for the CCMA. The report was commissioned by Mr Peter Codd, CCMA Program Manager for the NAP following a three-day workshop held at Colac on 21st to 23rd November 2001. The purpose of the workshop was to delineate the groundwater flow systems for the CCMA, according to the methodology outlined by the Bureau of Rural Sciences (BRS) (Coram, *et al.*, 2000; 2001). Approximately 55 invited experts and/or stakeholders in the groundwater and salinity issues in the CCMA region (Appendix A) attended the workshop, which was facilitated by Ray Evans, Phil Dyson and Darrel Brewin (all consultants) and organised by Jo Roberts (CCMA NAP Project Officer).

Purpose

The primary purpose of this report is to provide input to the development of CCMA NAP foundation projects and other programs, including (but not limited to):

- Renewal of the CCMA Regional Catchment Strategy
- Second Generation CCMA Salinity Action Plan
- CCMA Sub-catchment Salinity Risk Prioritisation
- CCMA Groundwater Monitoring and Research Database
- CCMA Groundwater Monitoring Guidelines and Review
- South West Water and Land-use Change Project

Scope

This report supersedes the GFS draft report issued on the 18th January 2002 (Dahlhaus Environmental Geology Pty Ltd report no. CCMA 02/01) and includes options for managing salinity. The information on the flow systems has been compiled from the data and advice provided by the experts at the workshop, with limited verification. Due to the time constraints of the workshop, information was not compiled on all the groundwater flow systems identified. Peter Dahlhaus compiled the GFS descriptions and attributes and Dave Heislers and Phil Dyson compiled the management options.

Continuous improvement

The workshop and report on the CCMA GFS should be regarded as the initial process in delineating groundwater flow systems as a tool for salinity management. It is expected that aspects of the GFS models described in this report will be superseded by updated research information within 12 months. As more information and data are provided through on-going research, all aspects of the GFS should be reviewed and the models modified where appropriate. The revised GFS information can be used to further refine the salinity risk priority areas and Salinity Action Plan.

2.0 Groundwater Flow Systems

The Groundwater Flow Systems (GFS) have been developed in the National Land and Water Audit (Audit) as a framework for dryland salinity management in Australia (NLWRA, 2001). They *"…characterise similar landscapes in which similar groundwater processes contribute to similar salinity issues, and where similar salinity management options apply"* (Coram, *et al.*, 2001). In Australia, twelve GFS have been identified on the basis of nationally distinctive geological and geomorphological character.

In the Audit, GFS are characterised by their hydrological responses and flow paths into local, intermediate and regional systems. This terminology should not be confused with that used in classic groundwater textbooks (eg. Freeze & Cherry, 1989; Fetter, 1994) for the nested flow systems in groundwater basins as described by Tóth (1963). In the terminology used by the Audit, local, intermediate and regional GFS are described by their response rate to hydrological change caused by alteration to the natural environment. The underlying assumption is that salinity is caused by increased recharge leading to rising groundwater tables, which have resulted from changes in land management over the past 200 years.

The Audit provides definitions of flow systems as tabulated below (Table 1).

Attribute	Rating	Meaning/Value
Scale	Local	Groundwater flows over distances <5km
	Intermediate	Groundwater flows over distances 5 – 30km
	Regional	Groundwater flows over distances > 50km
Aquifer transmissivity	Low	Less than 2 m^2/day
	Moderate	2 m^2/day to 100 m^2/day
	High	Greater than 100 m^2/day
Groundwater salinity	Low	Less than 2000 mg/l
	Moderate	2000 mg/l to 10000 mg/l
	High	Greater than 10000 mg/l
Catchment size	Small	Less than 10 km^2
	Moderate	10 km^2 to 500 km^2
	Large	Greater than 500 km^2
Annual rainfall	Low	Less than 400 mm
	Moderate	400 mm to 800 mm
	High	Greater than 800 mm
Salinity rating	S1	Loss of production
	S2	Saline land covered with salt-tolerant volunteer species
	S3	Barren saline soils, typically eroded with exposed sub-soils
Responsiveness to land management	Low	Salinity benefits accrue over timeframes > 50 years
	Moderate	Salinity benefits accrue over timeframes from 30 to 50 years
	High	Salinity benefits accrue over timeframes < 30 years

Table 1. GFS definitions in the Audit (NLWRA, 2001).

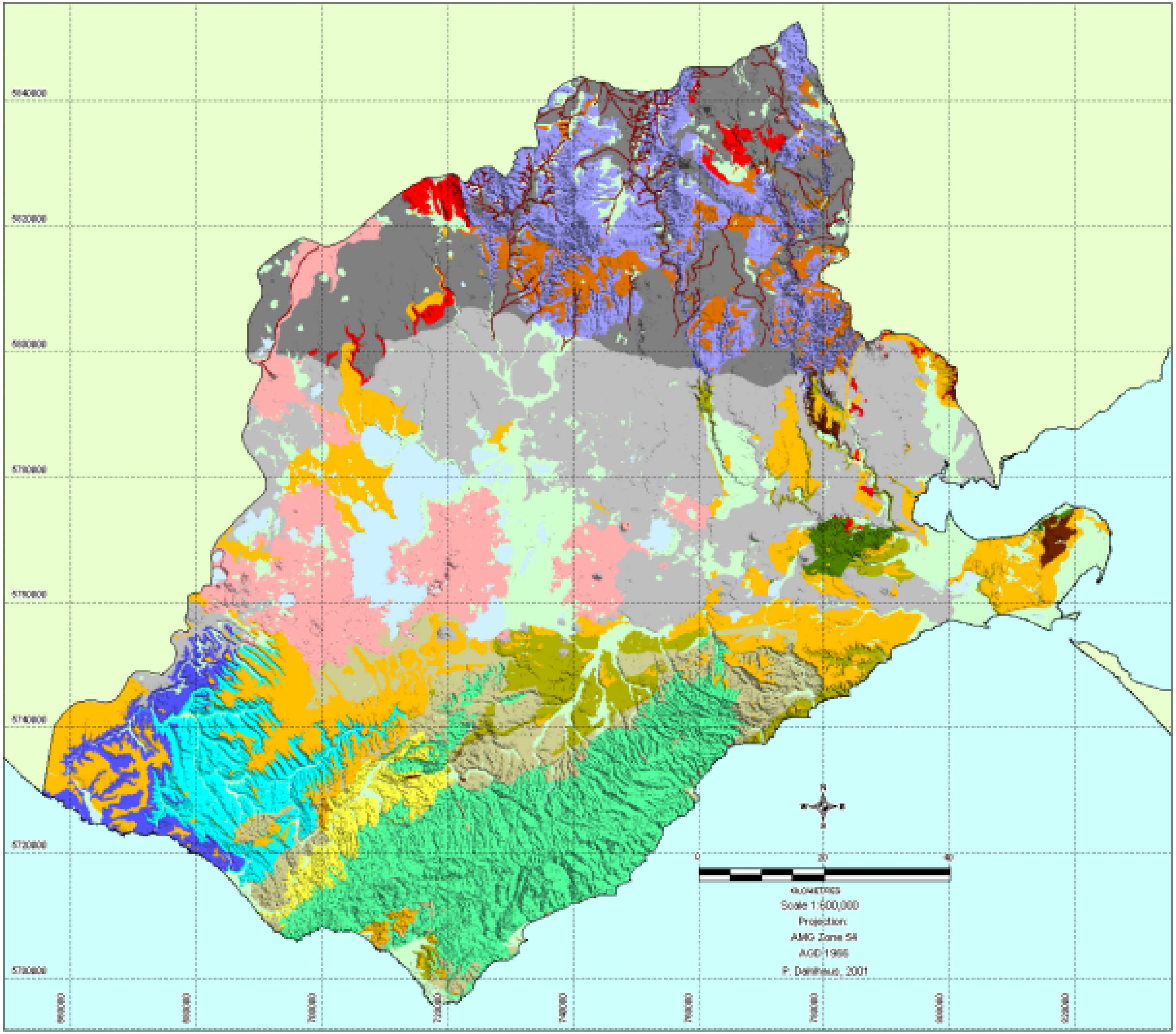
CCMA GFS

The 17 GFS recognised in the CCMA region are based on the outcomes of the November 2001 workshop and subsequent discussions with regional experts. It should be noted that the delineation of the groundwater flow systems for salinity management is not an attempt at a hydrogeological mapping, but rather the development of a tool for assessing the responsiveness of a catchment to salinity management options.

The spatial distribution of the CCMA GFS is shown overpage (Figure 1). The map has draped the GFS over the terrain model to demonstrate the relationship to the underlying landscapes.

Corangamite Catchment Management Authority region

Groundwater Flow Systems draped on terrain model



Elevation data model uses 20 m grid cells source data is 10 m contours from VicMap 1:25,000 topographic maps. Data processing by Tony Davidson, May 2001.

Image illumination:
Azimuth 45 degrees, inclination 45 degrees.
Vertical exaggeration x10 normal scale.
Image processing by Peter Dahlhaus.
Peter Dahlhaus - PhD project, 2001.

3.0 GFS descriptions

Each GFS has been described according to the attributes listed in the Audit (NLWRA, 2001) and the suggested description in the Evaluation Framework (Coram, Dyson & Evans, 2001). Additional descriptive information has been added in an attempt to add historical and landscape context to each system.

Individual GFS Map: An attempt has been made to delineate the spatial influence of each system (presented as a map) represented by the mapped outcrop and estimated sub-crop. The mapped outcrop has been derived from the 1:500,000 scale geological map as provided by the Geological Survey of Victoria (GSV) on their Victoria GIS CD released in November 2000. The estimated sub-crop distribution should be regarded as tentative at this stage and no attempt has been made to estimate sub-crop for some systems as yet. The delineation of sub-crop should improve considerably once the bore database is completed.

Region: This is stated in terms of the geographic and major geomorphic divisions.

Type areas: Two or three localities in the CCMA region when the GFS occurs.

Description: This is intended to provide a brief overview of the geology and groundwater flow, as well as the ‘salinity problem statement’ to provide context for the GFS’s role in the salinity issue.

Landscape attributes

Geology: Geological units derived from the GSV 1:500,000 digital geology map.

Topography: Description of the landforms of the GFS area.

Land Systems: Hierarchy of Land Systems derived from the 2002 revision by the Victorian Geomorphology Reference Group.

Regolith: General description of regolith materials.

Annual rainfall: Range in millimetres derived from rainfall model (Dahlhaus, 2002).

Dominant mid-1800s vegetation type: General description of native vegetation cover for the GFS area, derived from the Land Systems of Victoria (Rees, 2002).

Current dominant land uses: General description of land-uses with the GFS area.

Mapping method: Method used to delineate the GFS boundaries.

Hydrogeology

Aquifer type (porosity): Aquifer materials and porosity (primary or secondary porosity).

Aquifer type (conditions): Unconfined or confined.

Hydraulic Conductivity (lateral permeability): Range for hydraulic conductivity in m/d.

Aquifer Transmissivity: Range for transmissivity in m^2/d.

Aquifer Storativity: Range for storativity (dimensionless).

Hydraulic gradient: Descriptive indicator of hydraulic gradient (Steep, low, etc.).

Flow length: Range for flow lengths from recharge to discharge.

Catchment size: Estimation of flow systems area.

Recharge estimate: Recharge estimate in millimetres.

Temporal distribution of recharge: Estimate of when recharge occurs.

Spatial distribution of recharge: Estimate of where recharge occurs.

Aquifer uses: Description of groundwater use.

Salinity

Groundwater salinity: Salinity range in mg/l.

Salt store: Description of salt store in the GFS materials.

Salinity occurrence: Description of where salinity occurs.

Soil Salinity Rating: S1, S2, or S3, based on CLPR rating (Allen, 1996)

Salt export: Description of how the salt is exported (i.e. wash off from surface or baseflow to streams).

Salt impacts: Description of on-site or off-site impacts.

Risk

Soil salinity hazard: Estimation of soil salinisation hazard (High / medium / low).

Water salinity hazard: Estimation of water salinisation hazard (High / medium / low).

Major assets at risk: Descriptive list of CCMA region's assets at risk.

Responsiveness to land management: Estimation of hydrologic response (i.e. recharge response) to changes in land-management.

Management Options

Management options are stated in terms of biological management of recharge, engineering intervention for watertable control and productive uses of saline land and water (i.e. discharge management).

4.0 Discussion

Confidence in the options for salinity management in south west Victoria is constrained by the lack of scientifically validated models relating the assumed cause (land-use change) to the observed effect (salinity). There is growing evidence that land and water salinity was a more prevalent feature (than is assumed) of the landscape before widespread land-use change. In some areas, such as Lake Corangamite and associated wetlands, these primary saline areas are biodiversity assets of international importance. Confidence in management options for the protection of different classes of assets (agricultural land, water quality, biodiversity, infrastructure and cultural heritage) requires confidence in the conceptual model of how the salinity processes work.

One challenge in adopting the GFS approach to salinity management in the CCMA region is the recognition that the Audit's conceptual model does not hold for all areas of south west Victoria. In some areas (eg. Western Victorian volcanic plains, Heytesbury) the depth of the groundwater tables below the surface may be relatively unchanged over the past 200 years and other factors - such as changes to soil waterlogging and regolith hydrology - are implicated in the spread of salinity (Dahlhaus & MacEwan, 1997). In these areas, the systems are discharge-driven and recharge control is not considered as relevant to the management of salinity as the control of soil waterlogging and shallow, temporal water flows in the near-surface. In these GFS, the treatment of discharge areas can often result in a more productive outcome for agriculture or biodiversity in a shorter time frame than recharge control.

Recent research has developed a 2-dimensional numerical model (*Flowtube*) based on the GFS attributes for modelling catchment response scenarios (George, *et al.*, 2002). While this provides a useful tool to rapidly assess the response of a system, particularly given the limitations of scale and data quality, the tool cannot be used to determine where in the catchment management options should be targeted, or where salinity will occur. To improve the accuracy and usefulness of the scenario models, 3-dimensional models would be better, but require input data of a much higher quality.

5.0 Recommendations

This report represents the first attempt at delineating GFS for the CCMA region, based on the National framework for dryland salinity (Coram, *et al.*, 2000; 2001). While the delineation of the CCMA GFS has been the consensus of regional experts and the data on each GFS has been compiled with care, significant gaps in the data exist. Very little is known about some GFS and their role (if any) in salinity processes. To address these shortcomings, the following recommendations are made:

1. A review of the GFS for the CCMA should be undertaken once the information from concurrent projects is available. Four projects in particular, have the potential to add valuable information to the GFS descriptions, *viz:*
    - The groundwater monitoring and research database;
    - The groundwater monitoring guidelines and review
    - Corangamite CMA sub-catchment salinity risk prioritisation, and
    - The research and development compendium

    A review of the GFS within the next year is the most cost-effective (measured in money and time) means to improve the understanding of their role in salinity processes and their predicted response to management options.
2. Management options for the protection of all classes of assets need to be researched and included in the GFS descriptions. At present the salinity management options are biased toward the protection of agricultural land and stream water. Quite different options would be required for the protection of indigenous halophytic ecologies in primary saline areas, or the protection of building foundations, for example.
3. Priority should be given to research projects that can scientifically validate the assumed GFS for the CCMA region. Local GFS (i.e. highly responsive systems) with a significant salinity risk (eg. GFS 1 – Quaternary sediments) should be targets for immediate research aimed at proving the conceptual model and improving the confidence in the management options. Funding and commitment for long-term projects involving team research (eg. CSIRO, CRCs, Universities and Government research bodies) should be sought to improve the understanding of more complex systems (eg. GFS 14 - Volcanic plains basalt) and their role in salinity processes.
4. Scenario modelling for those systems with robust conceptual models (i.e. those GFS with a higher degree of confidence) would be useful to validate the assumed response of the suggested management options.
5. Consensus on GFS across boundaries with neighbouring CMAs should be checked.

Peter Dahlhaus

22nd May 2002

Acknowledgements

The participants in the GFS workshop (Appendix A) are thanked for their input. Subsequent discussions with John Leonard, Erica Nathan, Richard MacEwan and Peter Dixon were particularly helpful. Thanks to Mayavan Pillai for additional data.

References

ALLEN, M.J. 1996. Method for assessing dryland salinity in Victoria. *Centre for Land Protection Research Technical Report* **34**. 19p.

CORAM, J.E., DYSON, P.R., HOULDER, P.A. & EVANS, W.R. 2000? *Australian Groundwater Flow Systems contributing to Dryland Salinity*. A report prepared for the National Land and Water Resources Audit Dryland Salinity Project, Bureau of Rural Sciences, Canberra. 74p.

CORAM, J.E., DYSON, P.R. & EVANS, W.R. 2001. *An Evaluation Framework for Dryland Salinity*. A report prepared for the National Land and Water Resources Audit Dryland Salinity Project, Bureau of Rural Sciences, Canberra. 113p.

DAHLHAUS, P.G. 2002. Corangamite Catchment Management Authority. Atlas of GIS data. PhD project progress report (unpublished).

DAHLHAUS P.G. & MACEWAN R.J. 1997. Dryland Salinity in South West Victoria - Challenging The Myth. *in* (G.McNally, ed.) *Collected Case Studies in Engineering Geology, Environmental Geology, Hydrogeology*, Third Series, Geological Society of Australia Inc. pp. 165-181

FETTER, C.W. 1994. *Applied Hydrogeology*. 3rd edition, Macmillan College Publishing Company Inc., New York. 691p.

FREEZE, R.A. & CHERRY, J.A. 1979. *Groundwater*. Prentice-Hall inc. New Jersey. 604p.

GEOLOGICAL SURVEY OF VICTORIA. 2000. *Victoria GIS Data*. on 2 Compact Disks (CD), November 2000. Natural Resources and Environment, Melbourne.

GEORGE, R.J., CLARKE, C.J. & HATTON, T. 2001. Computer-Modelled Groundwater Response to Recharge Management for Dryland Salinity Control in Western Australia. *Advances in Environmental Monitoring and Modelling*, **2**/1, pp.3-35.

NLWRA 2001. *Australian Dryland Salinity Assessment 2000. Extent, impacts, processes, monitoring and management options*. National Land & Water Resources Audit. 129p

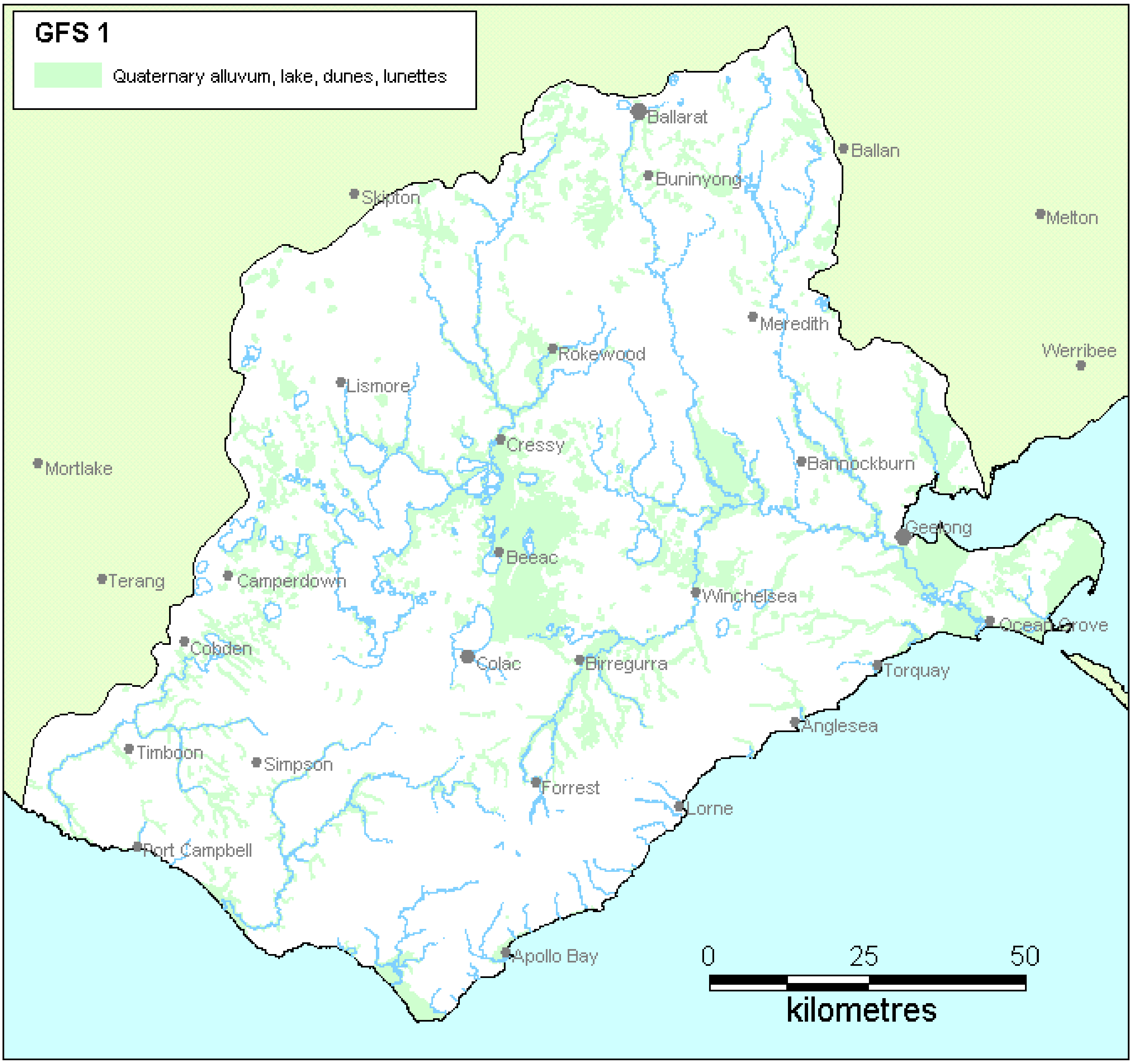
REES, D. 2002. Land Systems of Victoria. January 2000, Edition 3. *Centre for Land Protection Research Technical Report* **56**. 134p.

TÓTH, J.A. 1963. A theoretical analysis of groundwater flow in small drainage basins. *Journal of Geophysical Research* **68** (16). pp.4795-4812.

Groundwater Flow Systems

Number	Dominant Flow System	Sub-dominant Flow System	Description
GFS 1	Local		Quaternary sediments
GFS 2	Local		Scoria and stony rises
GFS 3	Local		Highlands gravel caps
GFS 4	Local		Heytesbury marls
GFS 5	Local		Gerangamete marls
GFS 6	Local		Otway Group rocks (Barrabool Hills)
GFS 7	Local		Palaeozoic granitic rocks
GFS 8	Local	Intermediate	Older Volcanics
GFS 9	Local	Intermediate	Otway Group rocks (Otway Range)
GFS 10	Intermediate	Local	Pliocene sands
GFS 11	Intermediate	Local	Wiridjil Gravels and equivalents
GFS 12	Intermediate	Local	Palaeozoic sedimentary rocks
GFS 13	Intermediate	Regional	Central Highlands volcanic rocks
GFS 14	Regional	Intermediate	Volcanic Plains basalt
GFS 15	Regional	Intermediate	Subsurface Deep Leads
GFS 16	Regional		Port Campbell Limestone
GFS 17	Regional		Dilwyn Formation

Local flow systems
in Quaternary sediments



Salt Swamp, Barwon Heads Road, Connewarre (composite photo).
This primary salinity site is part of the Lake Connewarre Conservation Reserve.

Local flow systems in Quaternary sediments

Region: All CCMA regions (Western Victorian Uplands, Western Victorian Plains and Southern Uplands)

Type areas: Beeac, Moolap, East of Lake Murdeduke

Description: Quaternary deposits of stream alluvium, hillside colluvium, swamp and lake deposits, lunettes, recent marine sediments and coastal dunes are widespread over the CCMA region. Although these deposits vary in thickness, formation and materials, they are grouped together by similar hydrogeological processes. Groundwater moves at varying rates through the unconsolidated deposits in local flow systems that develop at shallow depths below the ground surface. This GFS has the greatest area of mapped salinity in the CCMA region.

Salinisation in the lake and dune landscape is largely primary in origin. The clay lunettes fringing the lakes indicate salinisation episodes within these landscapes during the Pleistocene. Secondary salinisation takes the form of (a) expanded areas of primary salinisation; and (b) break of slope dune seepage. In addition elevated lake levels linked to climate or management activities may also result in periods of expanding salinisation through locally raised groundwater levels.

Primary salinity is a feature of the coastal and estuarine environments of the lower Barwon, Curdies, Gellibrand and Aire Rivers. The largest area occurs in the Lake Connewarre environs of the lower Barwon River, where the salinity has tidal influences. Prior to 1840, the tidal influences were noted as far upstream as Geelong and barrages were constructed in 1840 and 1898 to secure the quality of the emerging town's water supply. The Moolap Sunkland was covered by a shallow sea about 6000 years ago and may still have high storage of marine salts in the near-surface.

Landscape attributes

Geology: Dune, swamp and lake deposits (Qrd), alluvium (Qra), Pleistocene coastal dunes (Qpa).

Topography: River flats, swamps, lakes, lunettes, marshes, valley floors, river terraces, colluvial slopes, tidal lagoons, recent marine plains and lowlands, beach dunes

Land Systems:

2.0 Western Uplands:	6.0 Western plains
2.1 Dissected Uplands	*6.1 Volcanic Plains*
2.1.5 Alluvial terraces and floodplains	6.1.5 Lakes, swamps & lunettes
	6.1.6 Alluvial terraces and floodplains
	6.2 Sedimentary plains
	6.2.5 Alluvium, alluvial terraces, floodplains and coastal plains

Regolith: Unconsolidated gravel, sand, silt and clay.

Annual rainfall: 500 to 1500 mm

Dominant mid-1800s vegetation type: Grassland, Heathland, Scrub, Woodland and Forest, depending on location.

Current dominant land uses: Grazing, dairying, cropping, conservation, urban development.

Mapping method: Outcrop geology.

Hydrogeology

Aquifer type (porosity): Unconsolidated gravel, sand, silt and clay (primary porosity).

Aquifer type (conditions): Unconfined.

Hydraulic Conductivity (lateral permeability): Extremely variable. Probable range from 10^{-6} m/d to 10^{2} m/d.

Aquifer Transmissivity: Variable, in the moderate range. Estimated to be generally less than 20 m^2/d.

Aquifer Storativity: Extremely variable. Estimated to be from 0.001 to 0.05.

Hydraulic gradient: Varies with landscape. Very low to low in river and swamps, and moderate to locally steep in colluvium or lunettes.

Flow length: Generally short, but highly variable depending on local conditions. Ranges from a few metres up to one or two kilometres.

Catchment size: Generally small (<1 Ha to 100 Ha).

Recharge estimate: Unknown, but would vary with rainfall and landscape setting location.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Catchment wide.

Aquifer uses: Minor stock and domestic use from shallow bores.

Salinity

Groundwater salinity: Variable. Generally in the range of 3000 mg/l to 10000 mg/l.

Salt store: Moderate to high.

Salinity occurrence: Significant areas of primary salinity. Secondary salinity occurs as considerable expansion of primary salinity, and along lakeshores, low lying and flat areas, drainage lines, swampy wetlands, base of lunettes and dunes.

Soil Salinity Rating: S2, S3

Salt export: Wash off from surface.

Salt impacts: Mostly on-site. Some impacts off-site (eg. Lough Calvert drainage impacts on the Barwon River).

Risk

Soil salinity hazard: High. This GFS has the greatest area of mapped salinity.

Water salinity hazard: High.

Major assets at risk: Ramsar Wetlands, conservation areas, all major rivers, urban water supply (Ballarat & Geelong), engineering infrastructure, agricultural land.

Responsiveness to land management: Unknown, but should be very responsive.

Management Options

In areas of only moderate rainfall (eg. Beeac or Leslie Manor) perennial pastures offer a significant opportunity to control dune seepage. However, establishment of lucerne on lunette rises has been locally proven (eg. at Beeac) and perhaps offers the most productive outcome. Trees or shrubby vegetation in these situations cannot be ruled out but in many instances is beyond requirements.

Local low volume groundwater pumping within this GFS would probably work very well, but is likely to be a costly and excessive treatment.

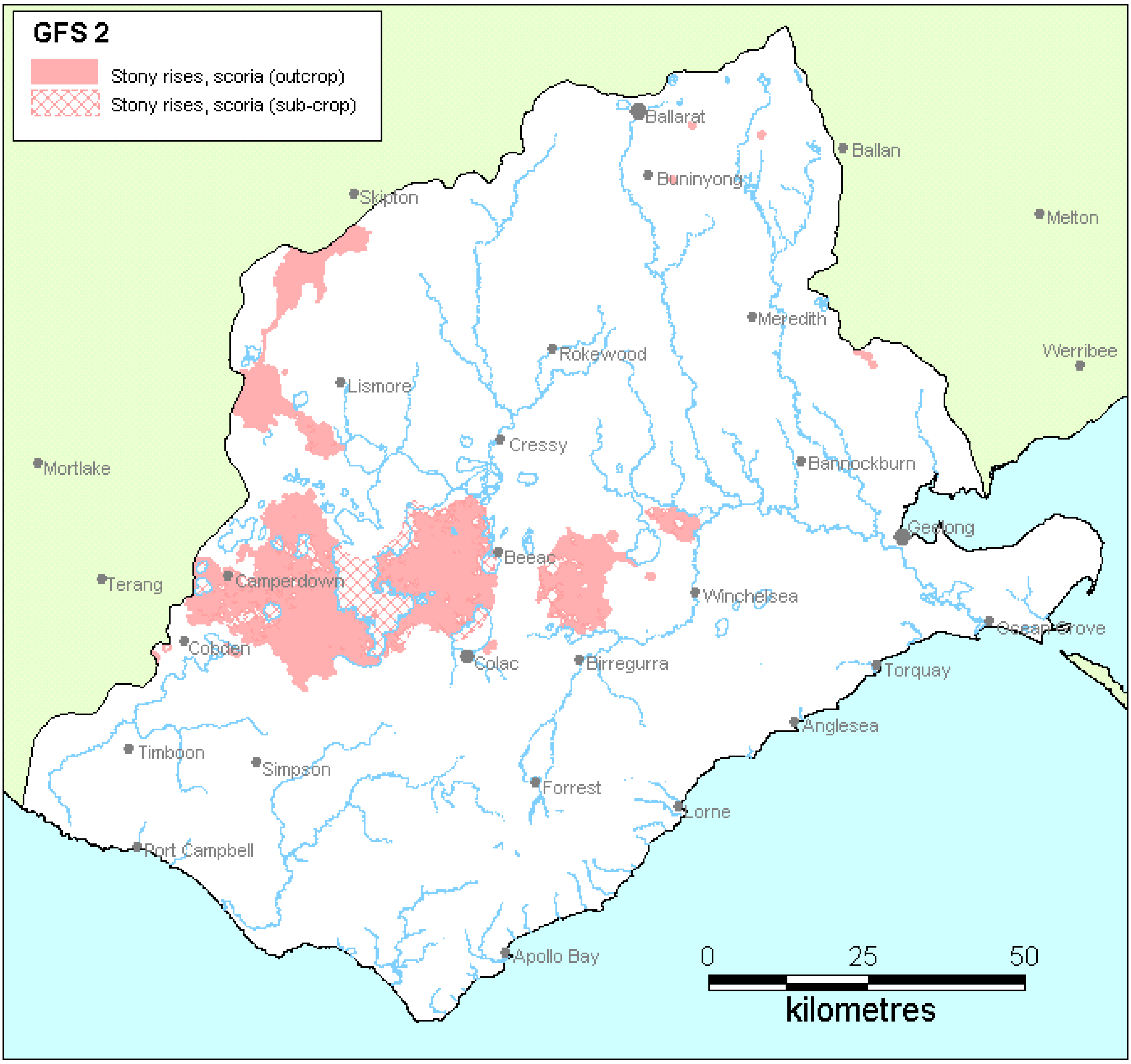
As saline areas will always remain a part of this landscape a significant level of attention will remain on saline agronomy opportunities. Given the 'wet' nature of this landscape application of salt tolerant grasses is probably more likely to succeed than halophytic types. The presence of relatively saline lake bodies means that saline aquaculture offers additional possibilities.

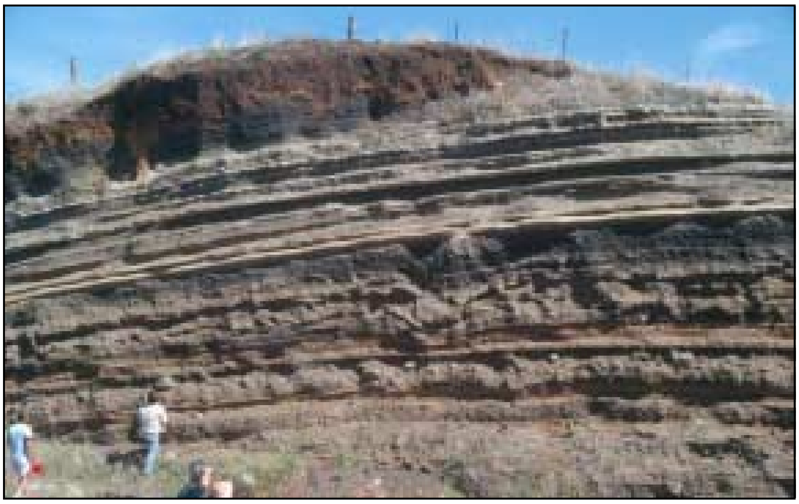
In many areas of primary salinity, management may be needed to retain the biodiversity values. Indigenous halophytic ecologies generally have a high conservation value, and are especially important in the larger estuarine wetlands of the lower Barwon and the Ramsar wetlands of the Volcanic Plains.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Comments**
Local flow systems in Quaternary sediments	Biological Management of recharge	Perennial pastures	Low to moderate – Highly suited below 700mm annual rainfall
		Crop management	Low to moderate – Potential for inter-cropping with lucerne
		Trees/woody vegetation	Moderate – Potential for groundwater interception through plantations
	Engineering intervention	Surface drainage	Low – Little ability to intercept surface water prior to it becoming recharge
		Groundwater pumping	Low to moderate – Limited opportunities where asset protection makes it warranted
	Productive uses of saline land and water	Salt tolerant pastures	Moderate to high – Salt tolerant grasses
		Halophytic vegetation	Low – Poorly suited to climate
		Saline aquaculture	Low to moderate – May be limited opportunities where there is sufficient groundwater and offsite salinity and nutrient issues can be managed
		Salt harvesting	Low – Groundwater is not sufficiently saline
		Others	See OPUS database (NDSP)

Local Flow Systems in scoria cones and stony rises





Highly porous and permeable tuff strata at Red Rock, Alvie.

Local Flow Systems in scoria cones and stony rises

Region: North and Central CCMA region (Western Victorian Uplands and Western Victorian Plains)

Type areas: Mt Warrenheip, Mt Elephant, Warrion, Dreeite, Pomborneit

Description: The scoria cones and stony rises in the northern and central part of the CCMA region were formed by the most recent volcanic eruptions. They have developed thin soils on the highly porous and permeable scoria and fractured basalt rocks. Groundwater moves through the fractured rocks and scoria at rapid rates and is quickly recharged by rainfall.

The scoria cones and stony rises probably have a more important role in water resource management than salinity. Scoria cones are often a local area of high recharge and often contain good quality groundwater that is a local irrigation resource (eg. Red Rock) or commercial spring water resource (eg. Mt Warrenheip). Natural springs often emerge at the break of slope that can feed adjacent wetland systems. Discharge from stony rises and at the boundaries of the lava flows (‘barriers’) often feeds lakes and wetlands in inter-rise depressions and contributes baseflow into adjacent streams. Their impact on recharging the underlying basalt aquifers (GFS 13 & GFS 14) is likely to be limited by their areal extent and any underlying clayey palaeo-soils.

Landscape attributes

Geology: Newer Volcanics scoria and basalt (Qvs) of Quaternary age.

Topography: Stony rises, lava ‘barriers’, scoria cones, tuff mounds, maars.

Land Systems:

6.0 Western Plains

6.1 Volcanic plains

6.1.1 Eruption points, including maars, scoria cones and lava shields

6.1.2 Stony rises.

Regolith: Thin stony soils (skeletal), gravely loams (scoria soils).

Annual rainfall: 500 to 900 mm

Dominant mid-1800s vegetation type: Woodland and grassland on stony rises, forests on the northern scoria cones.

Current dominant land uses: Conservation, grazing, cropping, viticulture, low-density urban development.

Mapping method: Outcrop geology, radiometric ternary ratio.

Stony Rises at Pomborneit. The landscape is characterised by no developed surface drainage and thin soils, leading to high groundwater recharge

Hydrogeology

Aquifer type (porosity): Fractured rock (secondary porosity), scoria (primary porosity)

Aquifer type (conditions): Unconfined

Hydraulic Conductivity (lateral permeability): Variable. Probably from 10^{-1} m/d (tighter pores and fractures) to 10^{2} m/d (open fractures and lava tubes).

Aquifer Transmissivity: Variable, but generally in the high range. Estimated to be generally less than 2000 m^2/d.

Aquifer Storativity: Variable. Estimated to be up to 0.20.

Hydraulic gradient: Estimated to be low (0.001) to moderate (0.01).

Flow length: Generally <5 km.

Catchment size: Generally small (<1000 Ha).

Recharge estimate: Unknown, but thought to be up to 100 mm annually.

Temporal distribution of recharge: Seasonal (winter and spring), with significantly more recharge in wetter years.

Spatial distribution of recharge: Catchment wide.

Aquifer uses: Significant use for stock and domestic purposes, some irrigation and mineral water extraction.

Salinity

Groundwater salinity: Generally in the range of 200 mg/l to 1000 mg/l.

Salt store: Low to very low.

Salinity occurrence: None within this GFS, but can occur at boundaries.

Soil Salinity Rating: Not applicable.

Salt export: Not applicable.

Salt impacts: Some recharge to underlying aquifers; Potential problem of up-coning intrusions of underlying saline groundwater due to pumping.

Risk

Soil salinity hazard: Possible risk to basalt plains salinity, depending on management

Water salinity hazard: Risk to stream and lake salinity, depending on management

Major assets at risk: Farm and irrigation water supply, stream quality, Ramsar Wetlands, conservation areas.

Responsiveness to land management: Thought to be rapid.

Management Options

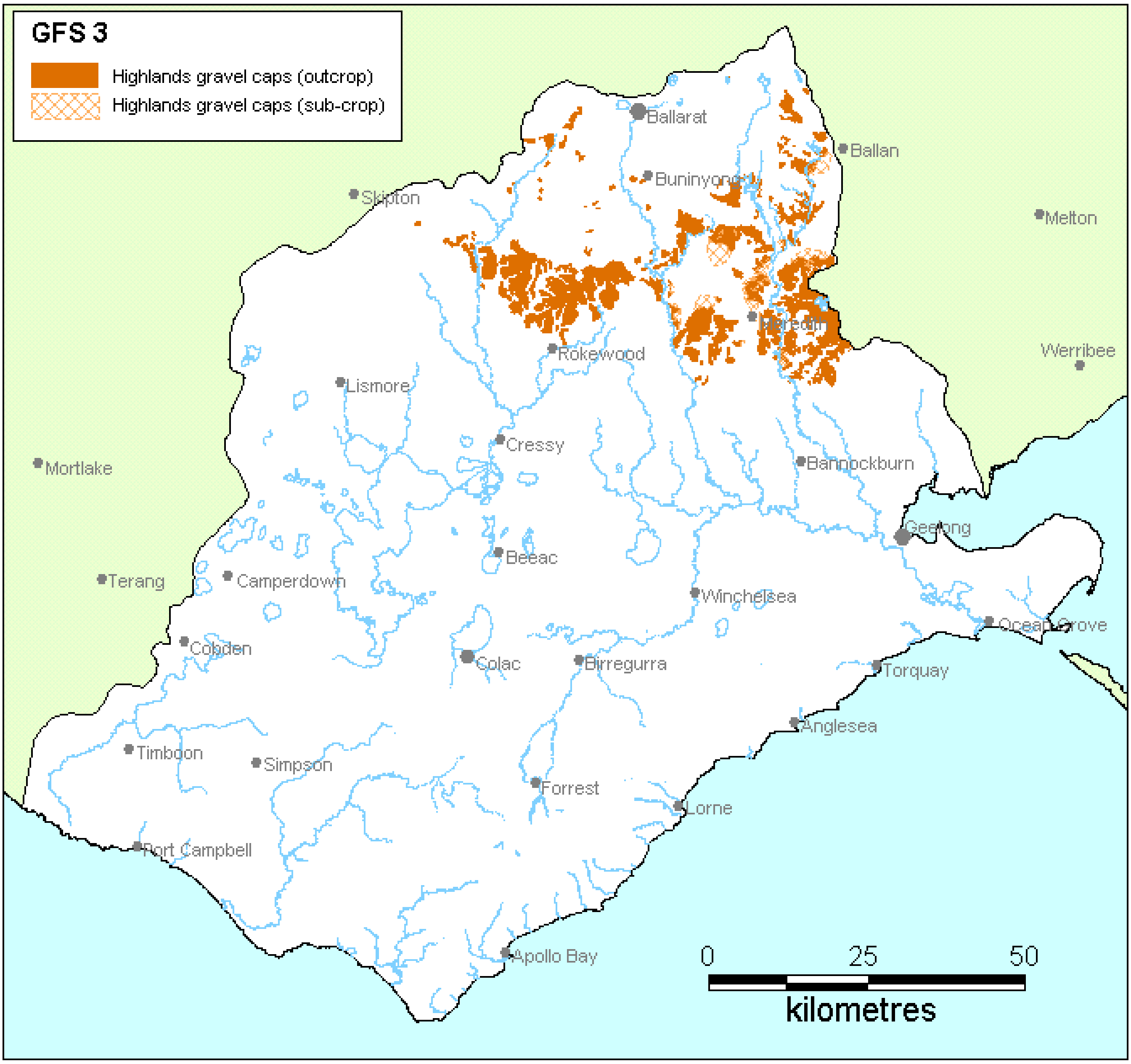
Both the stony rises ("barriers") and the scoria cones are areas of high recharge. However the freshwater discharge processes are a significant intrinsic characteristic of this landscape; so much so that the notion of recharge control should be a measured response. Evidence has emerged that the treeing of stony barriers may significantly reduce fresh and salt-diluting baseflows into streams (Richard MacEwan, *pers. comm.*). Similarly, draining inter-rise depressions and wetlands in these systems could result in increased soil salinisation potential, although this outcome is not well researched.

Ultimately salinity control strategies in this system are not well researched and may conflict with the need to maintain a commercial fresh groundwater resource and/or local and regional biodiversity. Some sense of how the scoria cone and stony rise country operated in its pristine environment would greatly assist this analysis.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	Options	Treatments	Comments
Local flow systems in Scoria cones and stony rises	Biological Management of recharge	Perennial pastures	Recharge management is not appropriate. In most instances the landscape is extremely permeable and contains fresh groundwater resources – groundwater management issues
		Crop management	
		Trees/woody vegetation	
	Engineering intervention	Surface drainage	Not appropriate
		Groundwater pumping	High – Suitable for groundwater extraction – groundwater management issues
	Productive uses of saline land and water	Salt tolerant pastures	N/a
		Halophytic vegetation	N/a
		Saline aquaculture	N/a
		Salt harvesting	N/a
		Others	N/a

Local Flow Systems in Highlands gravel caps



Local Flow Systems in Highlands gravel caps

Region: Northern CCMA region (Western Victorian Uplands)

Type areas: Bamganie, Napoleons, Snake Valley

Description: This GFS combines the gravel of generally Tertiary age which caps areas of the sedimentary rocks and granites in the northern CCMA region, and the minor deposits of Permian age glacial sands and gravels (tillite) in the north west CCMA region.

The deposits comprise chiefly quartz gravel and sand, often strongly ferruginised (forming ironstone and ferricrete) or silicified (forming silcrete), which exist as relatively thin remnant capping on the crests and gentle slopes of the Palaeozoic rocks. Groundwater generally moves slowly through the deposits in local flow systems. Owing to permeability constraints within the cemented gravels, groundwater flow is effectively short circuited into shallow and short flow paths that emerge at or near the base of the gravel exposures. These groundwater flow paths may vary from a few metres to hundreds of metres in length. Some vertical recharge into the underlying flow systems will also occur.

Management of the Highlands gravel caps GFS is important for reducing saline flows into the tributaries of the Barwon River system. Assumed rapid system responsiveness is likely to aid the impact of treatments in this system; and substantially reducing salt loads into the CCMA river systems would be a significant outcome.

Landscape attributes

Geology: Permian tillite (P), White Hills Gravel (Ppw), Werribee Formation sands (Pe), Moorabool Viaduct Formation and equivalents (Npb).

Topography: Ridge caps and gentle slopes.

Land Systems:

2.0 Western Uplands

2.1 Dissected uplands (Midlands)

2.1.3 Plateaux and low rises underlain by Cainozoic gravel

Regolith: Weathered gravels, sands and clays; ferruginised sands, ironstone gravels and ferricrete; occasional silcrete.

Annual rainfall: 600 to 750 mm

Dominant mid-1800s vegetation type: Forest and woodland.

Current dominant land uses: Grazing, conservation.

Mapping method: Outcrop geology, land systems and estimated sub-crop distribution.

Hydrogeology

Aquifer type (porosity): Gravels to fine sands, silts and clays (primary porosity), Ferruginised or silicified rock (secondary porosity).

Aquifer type (conditions): Unconfined, semi-unconfined to confined.

Hydraulic Conductivity (lateral permeability): Highly variable and largely unknown. Probably ranges from 10^{-4} m/d to 10 m/d.

Aquifer Transmissivity: Variable, but generally in the moderate range. Estimated to be generally less than 50 m^2/d.

Aquifer Storativity: Variable. Estimated to be from 0.05 to 0.20.

Hydraulic gradient: Estimated to be low (0.001). Could be locally steep at the edges of the gravel caps.

Flow length: Highly variable depending on local conditions. Generally a few tens to hundreds of metres but may be several kilometres in sub-crop (where confined by overlying basalts).

Catchment size: Estimated to be small (<10 Ha to 100 Ha).

Recharge estimate: Unknown.

Temporal distribution of recharge: In outcrop, the recharge is seasonal (winter and spring), with significantly more recharge in wetter years. Where overlain by basalts, slow recharge may occur throughout the year.

Spatial distribution of recharge: Catchment wide on outcrops and probably extensive leakage from overlying basalt (GFS13) in places.

Aquifer uses: Minor stock and domestic use.

Salinity

Groundwater salinity: Generally in the range of 1000 mg/l to 10000 mg/l.

Salt store: Moderate

Salinity occurrence: Generally at or near the base of the unit. Discharge mostly occurs along the boundaries of the unit.

Soil Salinity Rating: S2 to S3.

Salt export: Wash off from surface.

Salt impacts: Both on-site and off-site (from wash-off)

Risk

Soil salinity hazard: Moderate to High (scalding).

Water salinity hazard: Moderate.

Major assets at risk: Barwon River, Leigh River, Moorabool River, urban water supplies (Geelong and Ballarat), engineering and urban infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be high.

Management Options

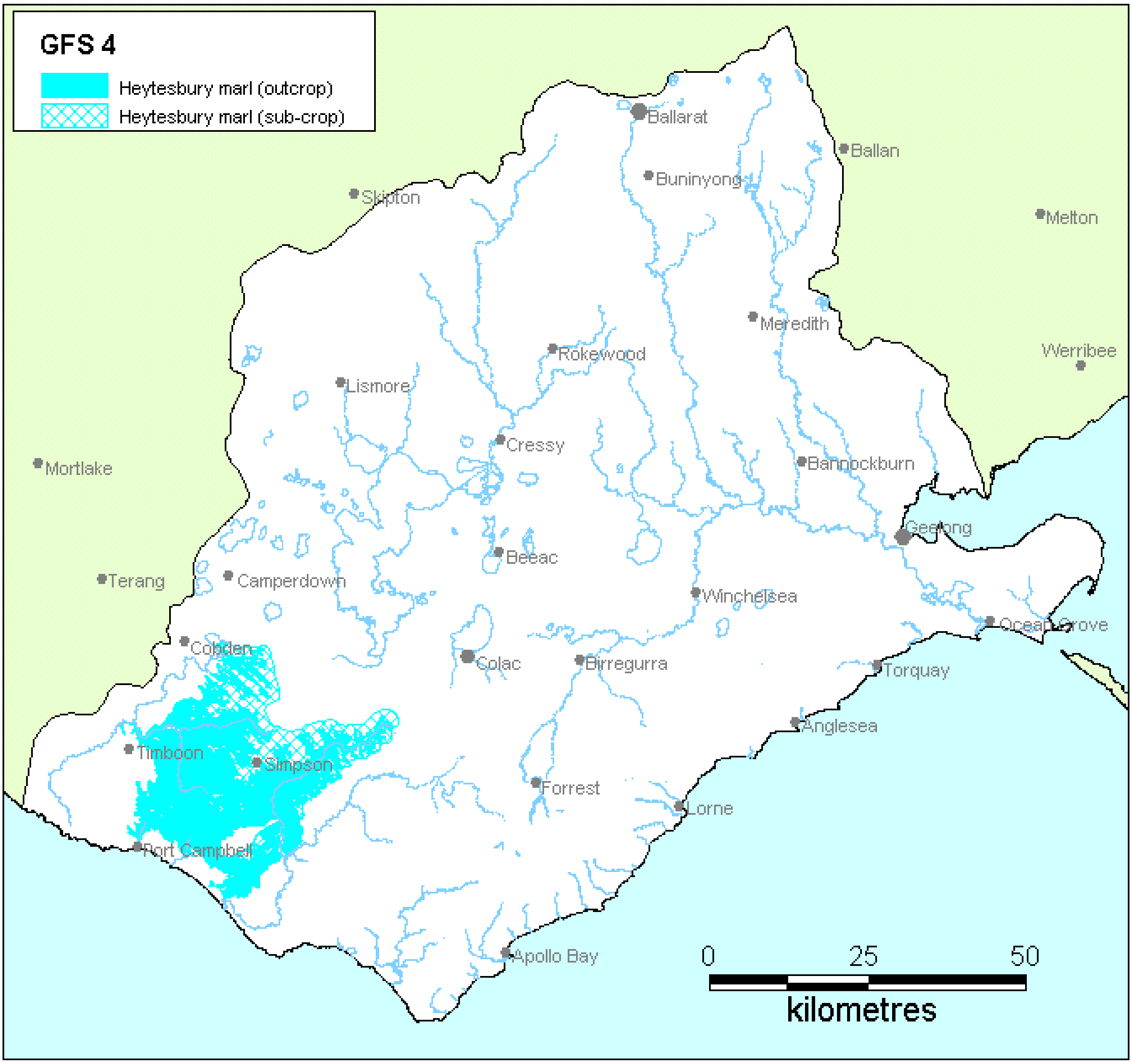
Many of the gravel caps were intermittently mined for gold from the mid 19th century to the early 20th century. This disturbance has possibly resulted in areas of preferential groundwater recharge, such as mine shafts and workings. From an agricultural perspective, the gravel caps are often landscape features that are degraded and marginal in value. This immediately questions the value of high input solutions especially with respect to perennial pastures. Isolating these areas and sowing to native grasses or trees may be preferable to the considerable investment that may otherwise be necessary.

Owing to the heterogeneity within this GFS engineering control of the groundwater has uncertain success, however surface drainage along contours or the break of slope may reduce the impact of discharge. Provided groundwater salinities are not too excessive this offers the possibility of dams and farm water supply. Salt tolerant grasses present the greatest opportunity for saline area treatment given the rainfall conditions.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	Options	Treatments	Comments
Local flow systems in Highlands gravel caps	Biological Management of recharge	Perennial pastures	Low – Low value in terms of high input pastures (due to degraded landscapes)
		Crop management	N/a
		Trees/woody vegetation	Low to moderate – Generally low salinity benefit for investment required, may improve in taking other NRM issues into account
	Engineering intervention	Surface drainage	Low – Highly permeable landscapes and difficult to intercept groundwater Moderate for discharge control.
		Groundwater pumping	Low to moderate – Depending on extent of aquifer development
	Productive uses of saline land and water	Salt tolerant pastures	Moderate – Salt tolerant grasses on saline seeps, existing technologies
		Halophytic vegetation	Low – Unsuitable climate
		Saline aquaculture	Low to moderate – Depends on extent of groundwater
		Salt harvesting	Low – Groundwater salinity too low
		Others	See OPUS database (NDSP)

Local Flow Systems in the Heytesbury marls



S1 salinity developed along drainage lines near Newfield.

Local Flow Systems in the Heytesbury marls

Region: Southern CCMA region (Western Victorian Plains)

Type areas: Simpson, Cooriemungle

Description: The Heytesbury marls are thick marine deposits that form the slopes and valleys of the Heytesbury region. The blue-grey marl weathers to highly plastic orange-brown clay, which is very prone to landslides. The vast majority of the GFS is comprised of Gellibrand Marl, with the minor deposits of Narrawaturk Marl and Demons Bluff Formation forming the remainder.

At depth, groundwater moves very slowly through the deposits and is pressurised by the potentiometric head in the underlying Dilwyn Formation (GFS 17). Effectively, the marls are at or near 100% saturation to very shallow depths. Local flow systems develop in the near surface (regolith) and the occurrence of salinity in some areas is believed to be associated with the distribution of landslides.

The limited research to date indicates that at least two local groundwater flow systems operate in this landscape:

- a very localised shallow "perched" and probably seasonal groundwater system associated with the redistribution of the overlying Pliocene sands (GFS 10) through landslides, and the damming of groundwater within the sand lenses.
- an underlying watertable consisting of a multitude of local groundwater flow cells that are generally contained within 20-30m of the ground surface

These flow systems are nested within the larger regional flow system hydraulically connected to the underlying Dilwyn Formation.

Landscape attributes

Geology: Gellibrand Marl (Nmn), Narrawaturk Marl (Pon), Demons Bluff Formation (Ped)

Topography: Dissected coastal plain, gentle hills, steeper valleys.

Land Systems:

6.0 Western Plains

6.1 Sedimentary plains

6.1.2 Dissected plains

Regolith: Weathered marl with numerous landslides.

Annual rainfall: 800 to 1000 mm

Native landscape: Forest on hillslopes, woodland and shrubland on valley floors.

Current dominant land uses: Dairying, some grazing and conservation.

Mapping method: Outcrop geology and estimated sub-crop distribution.

Hydrogeology

Aquifer type (porosity): Fine calcareous sands, silts and clays (primary porosity), tension cracks and shear failure surfaces created by landslides and desiccation cracks (secondary porosity).

Aquifer type (conditions): Unconfined, with minor areas semi-confined

Hydraulic Conductivity (lateral permeability): Variable. Probable range from 10^{-6} m/d to 10^{-2} m/d

Aquifer Transmissivity: Variable, in the low range. Estimated to be generally less than 0.10 m^2/d.

Aquifer Storativity: Variable. Estimated to be from 0.01 to 0.05.

Hydraulic gradient: Varies with landscape. Can be locally steep.

Flow length: Highly variable depending on local conditions. Ranges from less than half a kilometre up to three kilometres.

Catchment size: Generally small (200 Ha to 500 Ha).

Recharge estimate: Unknown, but could be up to 150 mm/yr.

Temporal distribution of recharge: Seasonal (winter and spring), with significantly more recharge in wetter years and following antecedent dry periods (recharge through desiccation cracks and pugged soils)

Spatial distribution of recharge: Catchment wide on outcrops and probably extensive leakage from overlying Pliocene sands (GFS 10) in places.

Aquifer uses: Very little. Possibly some stock and domestic use.

Salinity

Groundwater salinity: Generally in the range of 300 mg/l to 6000 mg/l.

Salt store: Moderate to high.

Salinity occurrence: Drainage lines, below landslide slip planes, break of slope and hillside ‘seeps’.

Soil Salinity Rating: S1 to S2.

Salt export: Wash off from surface and baseflow to streams.

Salt impacts: Both on-site and off-site.

Risk

Soil salinity hazard: Moderate.

Water salinity hazard: Moderate.

Major assets at risk: Gellibrand River, Curdies River, engineering infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be slow.

Management Options

Given that the combined groundwater system is saturated to the near-surface, effective recharge control is unlikely in this landscape due to (a) its natural state being a low storage system within a high rainfall environment; and (b) for practical reasons as the region forms a high value intensive agricultural dairy industry that is unlikely to absorb extensive reafforestation. High rainfall renders perennial pastures as ineffective.

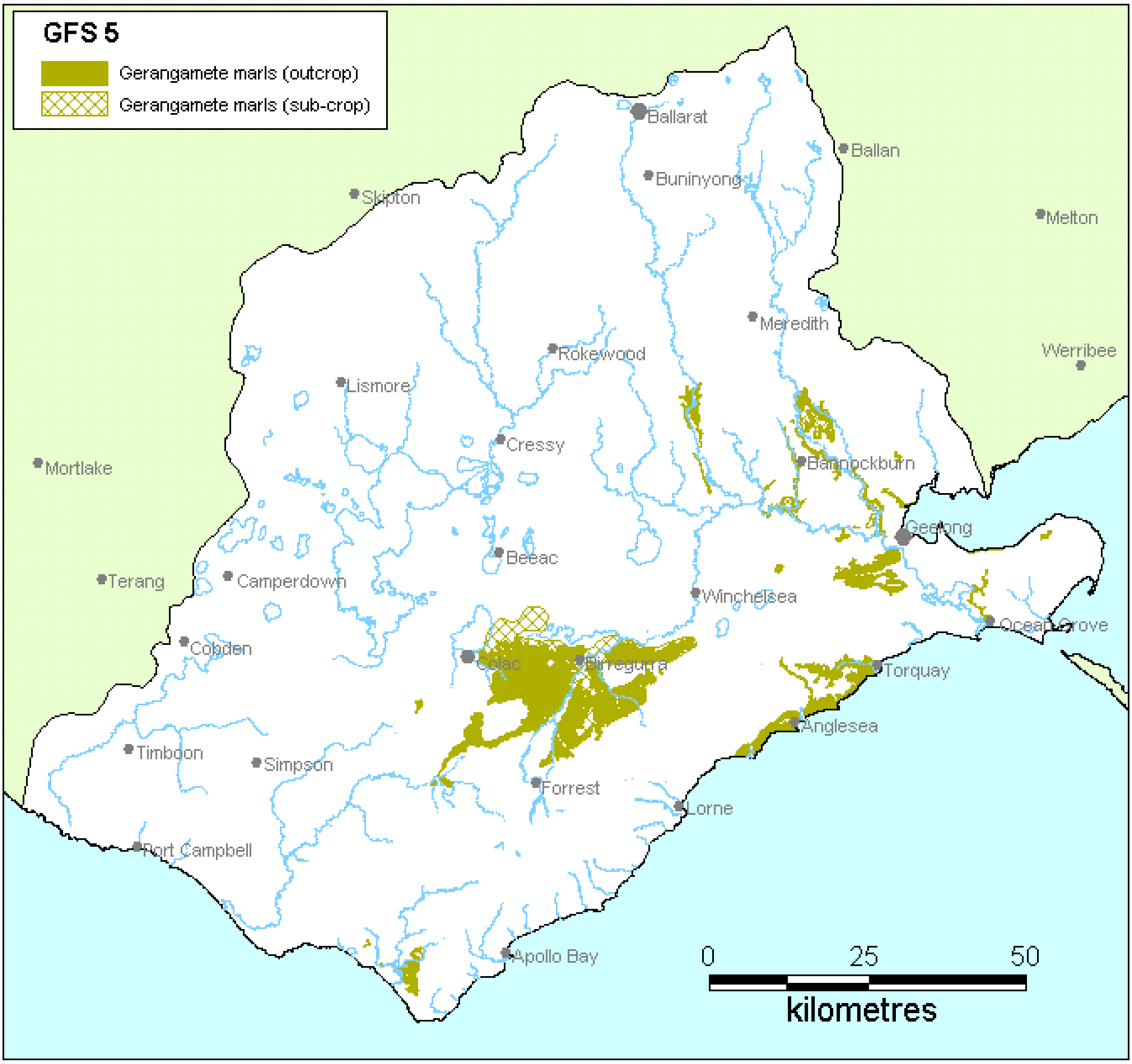
Strategic tree planting along contours may intercept lateral groundwater flow from both the perched groundwater and the regional watertable systems; thereby somewhat reducing shallow groundwater accumulation and waterlogging in the lower landscape. However, it is the broader benefits of tree belts that should be evaluated for their establishment rather than the expectation of significant salinity benefit. The model case study for tree belt plantings in the Heytesbury is the Simpson Agroforestry Site. Evidence for salinity and waterlogging amelioration due to tree belts is difficult to establish given the climatic patterns to date.

Sub-surface drainage in some instances has proved an economically affordable option with significant waterlogging reduction impacts. However, the instream impacts (flow and water quality) of broad scale drainage have yet to be adequately reconciled. Treatment of saline land needs to acknowledge the severe seasonal waterlogging and nutrient management problems in this landscape.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Ranking**
Local flow systems in Heytesbury marls	Biological management of recharge	Perennial pastures	Low – Rainfall too high for effective recharge management
		Crop management	N/a
		Trees/woody vegetation	Low to moderate – Tree belts only practical option with limited impacts
	Engineering intervention	Surface drainage	Low to moderate – May help reduce waterlogging in saline land
		Sub-surface drainage	Moderate - waterlogging and productivity benefits identified; Tight drain spacing pushes economics
		Groundwater pumping	Low – Low permeability landscapes and very poor aquifers
	Productive uses of saline land and water	Salt tolerant pastures	High – Suited to treatments with salt tolerant grasses that are tolerant of waterlogging
		Halophytic vegetation	Low – Climate is not supportive
		Saline aquaculture	Low – Difficulties extracting saline groundwater resources
		Salt harvesting	Low – Climate is not appropriate and aquifers do not support pumping
		Others	Low – most salt affected areas are too small, and the landscape does not support groundwater extraction

Local Flow Systems in the Gerangamete marls



S1 and S2 salinity at the salinity research site, Dewings Bridge Road, Gerangamete (composite photo). Trees on the horizon have been planted for salinity control.

Local Flow Systems in the Gerangamete marls

Region: Southern CCMA region (Western Victorian Plains)

Type areas: Gerangamete, Barwon Downs

Description: The Gerangamete marls are thick marine deposits that form the broad valley of the Barwon River in the Barwon Downs region. Gellibrand Marl makes up the majority of the GFS, with the Demons Bluff Formation, Jan Juc Formation and Narrawaturk Marl as minor components. In the regolith, the blue-grey marl is weathered to plastic orange-brown clay.

At depth, groundwater moves very slowly through the deposits and which are pressurised by the potentiometric head of the underlying Dilwyn Formation (GFS 17). Consideration of treatment in this landscape requires an understanding that the effective groundwater system contributing to surface salinisation is comprised of localised groundwater flow cells that are contained within 20 to 30 metres of the ground surface. These local flow systems are nested within a regional system which is saturated to the near-surface.

Landscape attributes

Geology: Gellibrand Marl (Nmn), Demons Bluff Formation (Ped), Jan Juc Formation and Narrawaturk Marl (Pon)

Topography: Low rolling hills.

Land Systems:

- 3.0 Southern Uplands
  - *3.3 Dissected low hills*
    - 3.3.2 Rolling hills

Regolith: Weathered marl.

Annual rainfall: 700 to 900 mm

Dominant mid-1800s vegetation type: Forest and woodland.

Current dominant land uses: Dairying, grazing, conservation.

Mapping method: Outcrop geology and estimated sub-crop distribution.

Hydrogeology

Aquifer type (porosity): Fine calcareous sands, silts and clays (primary porosity).

Aquifer type (conditions): Unconfined, with small areas semi-unconfined

Hydraulic Conductivity (lateral permeability): Variable. Probable range from 10^{-6} m/d to 10^{-2} m/d.

Aquifer Transmissivity: Variable, in the low range. Estimated to be generally less than 0.10 m^2/d.

Aquifer Storativity: Variable. Estimated to be from 0.01 to 0.05.

Hydraulic gradient: Moderate, but varies with landscape. Can be locally steep.

Flow length: Highly variable depending on local conditions. Ranges from less than 500 metres up to 3 kilometres.

Catchment size: Generally small (200 Ha to 500 Ha).

Recharge estimate: Unknown, but could be up to 100 mm/yr.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Catchment wide on outcrops with some leakage from overlying Pliocene sands (GFS 10) in places.

Aquifer uses: Very little. Possibly some stock and domestic use.

Salinity

Groundwater salinity: Generally in the range of 1500 mg/l to 6000 mg/l.

Salt store: Moderate to high.

Salinity occurrence: Lower slopes and drainage lines.

Soil Salinity Rating: S2.

Salt export: Wash off from surface and baseflow to streams.

Salt impacts: Both on-site and off-site.

Risk

Soil salinity hazard: Moderate.

Water salinity hazard: Moderate.

Major assets at risk: Barwon River, urban water supply (Geelong), engineering infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be slow.

Management Options

In practical terms effective recharge control is unlikely in this landscape owing to its natural predisposition as a low storage system within a high rainfall environment. High rainfall renders perennial pastures as ineffective in this landscape. Given suitable investment conditions plantation agroforestry would have a practical and significant role in recharge management, though justification of this enterprise on the basis of the salinity benefit is questionable.

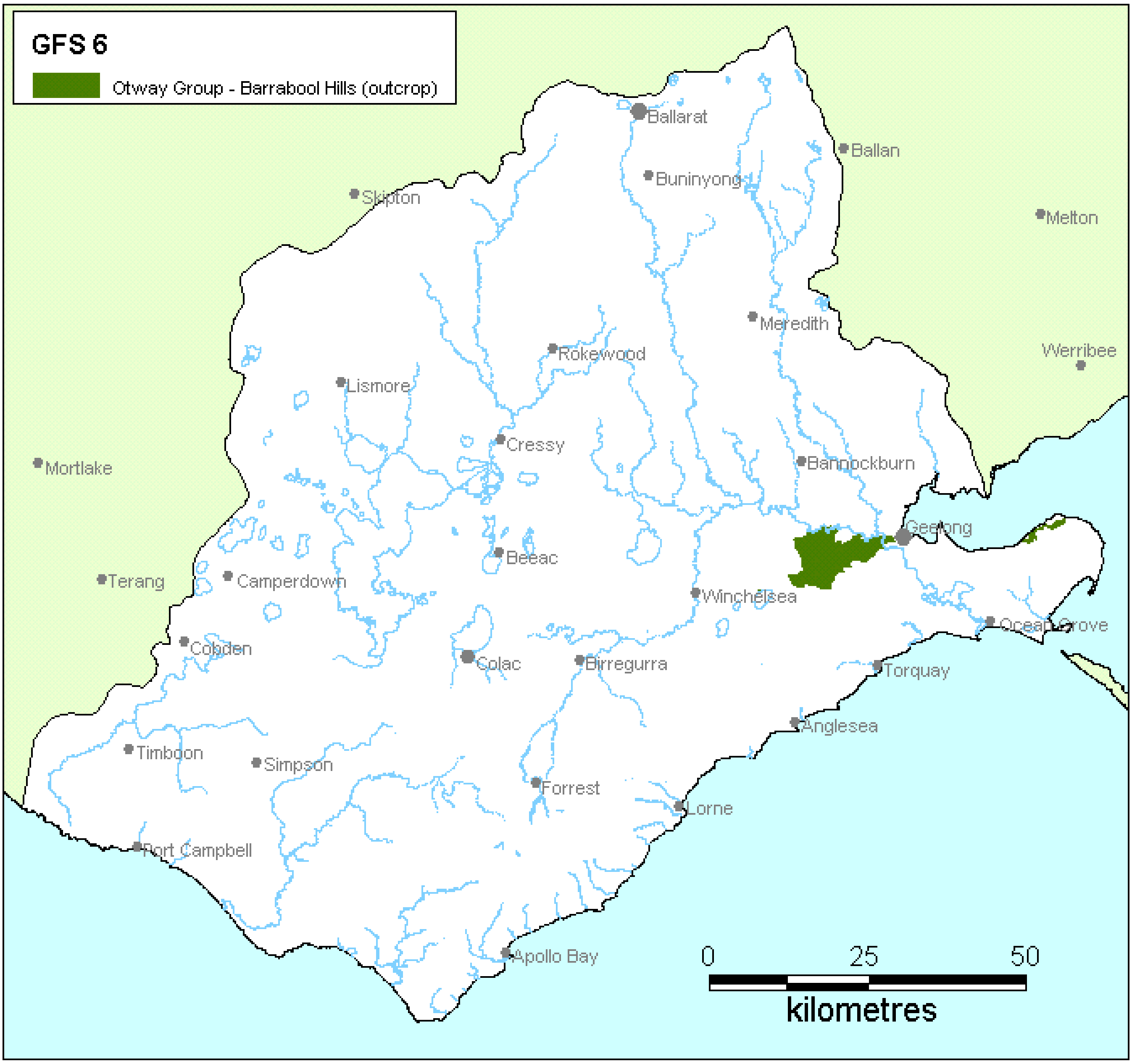
However, strategic tree planting along contours may have the opportunity to intercept lateral groundwater flow (a) seasonally from the soil zone (A_2 horizon); and (b) from the shallow watertable, thereby somewhat reducing shallow groundwater accumulation and waterlogging in the lower landscape. However, it is the broader benefits of tree belts that should be the driver for their establishment rather than the expectation of significant salinity benefit. The model case study for tree belt plantings in this flow system is the Gerangamete Agroforestry Site. Evidence for salinity and waterlogging amelioration impacts from the tree belts is difficult to establish especially given the extenuating climatic patterns since the mid 1990s.

Engineering intervention is limited by (a) permeability constraints within the Gellibrand Marl; and (b) the water quality implications for the Barwon system. Treatment of saline land needs to consider that there is severe seasonally waterlogging in this landscape.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	Options	Treatments	Ranking
Local flow systems in the Gerangamete marls	Biological management of recharge	Perennial pastures	Low - Rainfall too high for effective recharge management
		Crop management	N/a
		Trees/woody vegetation	Moderate – May afford some benefit in the longer term when combined with surface water management
	Engineering intervention	Surface drainage	Low to moderate – May improve saline lands by reducing water logging
		Sub-surface drainage	
		Groundwater pumping	Low – Low permeability landscapes with poor aquifers
	Productive uses of saline land and water	Salt tolerant pastures	Moderate to high – Salt tolerant grasses
		Halophytic vegetation	Low – Climate not appropriate
		Saline aquaculture	Low – Groundwater extraction too difficult
		Salt harvesting	Low – Climate not appropriate and generally poor aquifers
		Others	Low – most salt affected areas are too small, and the landscape does not support groundwater extraction

Local Flow Systems in the Otway Group rocks (Barrabool Hills)



S1 and S2 salinity along a tributary of Waurn Ponds Creek, Devon Road, Barrabool Hills.

Local Flow Systems in the Otway Group rocks (Barrabool Hills)

Region: Southern CCMA (Southern Victoria Uplands)

Type areas: Barrabool Hills, Bellarine Peninsula (Clifton Springs)

Description: The lithic sandstone and mudstone rocks of the Cretaceous age Otway Group occur in outcrop over the majority of the Barrabool Hills and locally on the Bellarine Peninsula. They have been deeply weathered and are covered by residual clay soils. Groundwater flows through the fractured rocks and regolith in local flow systems. Salinity occurs along drainage lines and at the break of slope.

Though well documented in terms of discharge mapping, the actual salinity hazards posed within this GFS are poorly understood. However, given that the urban fringe of the City of Greater Geelong encroaches upon the eastern foot slopes of the Barrabool Hills and the landscapes of this GFS drain into the Barwon River, the salinity risk of this GFS requires urgent research.

Landscape attributes

Geology: Otway Group (Kl).

Topography: Rounded hills.

Land Systems:

3.0 Southern Uplands.

3.2 Dissected uplands

3.2.2 Dissected ranges

Regolith: Clay soils over deeply weathered sandstones and mudstones

Annual rainfall: 500 to 700 mm

Dominant mid-1800s vegetation type: Forest

Current dominant land uses: Grazing, cropping, conservation, urban.

Mapping method: Outcrop and estimated sub-crop distribution.

Hydrogeology

Aquifer type (porosity): Fractured rock (secondary porosity); regolith (primary porosity)

Aquifer type (conditions): Unconfined to semi-confined.

Hydraulic Conductivity (lateral permeability): Largely unknown. Estimated range from 10^{-5} m/d to 1 m/d.

Aquifer Transmissivity: Generally less than 50 m^2/d.

Aquifer Storativity: Estimated range from 0.01 to 0.03.

Hydraulic gradient: Generally moderate to steep. Locally very steep in valleys.

Flow length: Estimated up to 5 kilometres.

Catchment size: Estimated to be <1000 Ha.

Recharge estimate: Unknown.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Thought to be higher on rounded crests.

Aquifer uses: Some stock and domestic use.

Salinity

Groundwater salinity: Ranges from 2000 mg/l to 8000 mg/l.

Salt store: High.

Salinity occurrence: Drainage lines and break of slope.

Soil Salinity Rating: S1, S2

Salt export: Mainly baseflow to streams.

Salt impacts: Unknown. Possible off-site (baseflow).

Risk

Soil salinity hazard: Low.

Water salinity hazard: Unknown, probably Low.

Major assets at risk: Barwon River, conservation wetlands.

Responsiveness to land management: Unknown

Management Options

The local groundwater flow systems provide the ability to achieve some level of salinity control in this landscape, though the response times will likely be tempered by the effect of relatively deep weathered profiles.

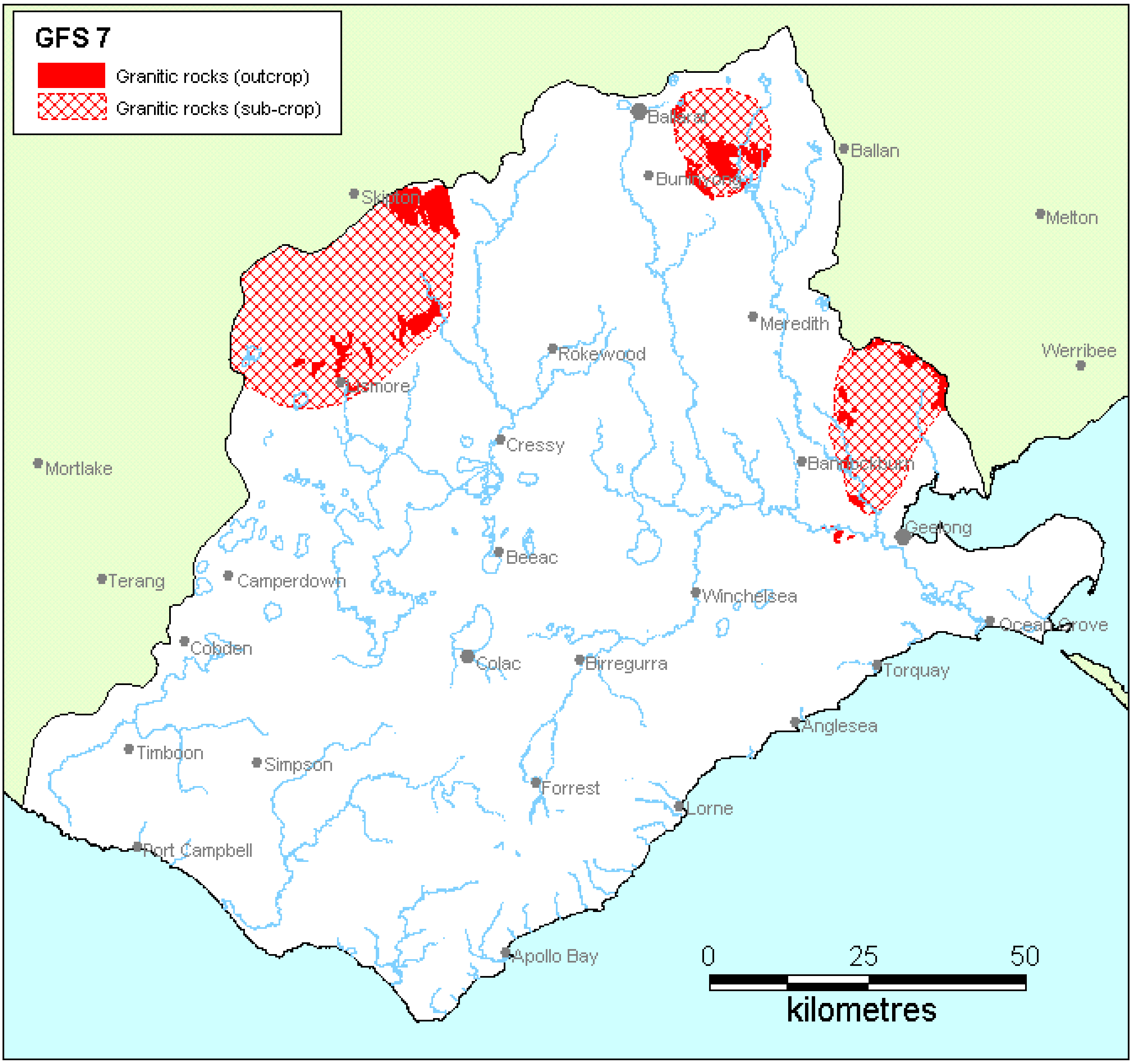
The value of perennial pastures in reducing recharge for salinity control is generally likely to be marginal given that the rainfall approaches 700 mm, though some areas where there is a rain shadow aspect (i.e. eastern slopes) provide better opportunities. In areas where soil conditions are suitable, lucerne offers considerable promise in its own right, but also as a rotation within a cropping system. Block plantings of trees offer a management opportunity if the economics allow this to be incorporated into a farming system on a sufficiently broad scale.

Engineering solutions are not amenable as a broadscale salinity control opportunity, but may be considered within the context of protecting a discrete asset.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Comments**
Local flow systems in the Otway Group rocks (Barrabool Hills)	Biological Management of recharge	Perennial pastures	Low to moderate – Suitable climatically, but uncertain responsiveness
		Crop management	Low to moderate – Inter-cropping with lucerne???
		Trees/woody vegetation	Low to moderate – Difficult to see where they would provide a benefit this landscape
	Engineering intervention	Surface drainage	Low – Difficult to see where drainage might reduce recharge or waterlogging on saline lands
		Groundwater pumping	Low to moderate – May be an option where high value (perhaps urban) assets are to be protected
	Productive uses of saline land and water	Salt tolerant pastures	Moderate – Salt tolerant grasses with existing technologies
		Halophytic vegetation	Low- Poorly suited to the climate
		Saline aquaculture	Low to moderate – Issues of groundwater extraction and salt and nutrient management
		Salt harvesting	Low – Groundwater salinity too low
		Others	See OPUS database (NDSP)

Local Flow Systems in granitic rocks



S1 and S2 soil salinity in drainage line, Francis Lane, Pittong.

Local Flow Systems
in granitic rocks

Region: Northern CCMA region uplands (Western Victorian Uplands)

Type areas: Pittong, Lismore

Description: The granitic rocks in the northern part of the CCMA region were formed around 350 million years ago when granitic magma cooled slowly at depths of two to five kilometres within the sedimentary rocks. The resulting crystalline rocks are now exposed by extensive erosion. Deep weathering has created a variable regolith comprising thick kaolin clay in places, and sandy grus or granite tors elsewhere.

The granitic rock GFS is typically characterised by deeply weathered clays overlying hard fractured granite. These landscapes are dominated by localised groundwater flow cells contained within the granite system (eg. Pittong) apart from the exceptions of (a) upward movement of groundwater along fractures providing discharge of assumed deeper circulating saline groundwater of unconfirmed source (as observed at Pitting) and (b) vertically recharged sub-surface granite that subsequently outcrops and discharges into numerous streamlines (as observed in the Lismore district).

Typically, sub-surface water movement in this GFS occurs through a variety of pathways and processes. Ephemeral fresh-water springs are a feature of the landscapes around Pittong following heavy or prolonged rainfall. In areas with well-developed A_2 horizons in the soil profile, seasonal lateral flow is significant. In general, the groundwater flow systems are saturated to the near-surface and they are superimposed by seasonal shallow waterlogging of the low permeability clays. Groundwater flow is sluggish through the clayey profile, but may be enhanced by a more permeable 'transitional' aquifer sitting immediately above the fresh fractured rock aquifer system. Groundwater discharge in the broad valleys at Pittong is probably a function of all the above flow scenarios.

Landscape attributes

Geology: Devonian granite, granodiorite, adamellite (Dlg, Dug), Ceres Gabbro (Ev).

Topography: Gently undulating low hills, broad valleys, can be locally steep.

Land Systems:

- 2.0 Western Uplands
  - *2.1 Dissected uplands* (Midlands)
    - 2.1.2 Ridges and plateaux, hills and valley slopes associated with granitic rocks and aureoles

Regolith: Highly variable deeply weathered profile (soil, grus, saprolite, tors).

Annual rainfall: 550 to 750 mm

Dominant mid-1800s vegetation type: Woodland and forest

Current dominant land uses: Grazing, forestry, mining, conservation

Mapping method: Outcrop geology and estimated sub-crop

Hydrogeology

Aquifer type (porosity): Fractured rock and saprolite (secondary porosity), soil and grus (primary porosity).

Aquifer type (conditions): Unconfined and semi confined.

Hydraulic Conductivity (lateral permeability): Highly variable. Estimates for each component are: saprolite varies from approximately 10^{-6} m/d to 10^{-1} m/d, grus varies from 10^{-3} m/d to 10^{-1} m/d, and the rock varies from 10^{-10} m/d to 10^{-2} m/d.

Aquifer Transmissivity: Highly variable in the low to moderate range. Estimated to be generally less than 50 m^2/d.

Aquifer Storativity: Variable. Estimated to be less than <0.05 for saprolite and grus and <0.01 for the fractured rock.

Hydraulic gradient: Estimated to be moderate to locally steep.

Flow length: Generally less than 5 kilometres.

Catchment size: Small (~<500 Ha) to moderate (>1000 Ha).

Recharge estimate: Unknown. May be approximately 25 mm annually.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Catchment wide but varies with the depth of regolith, slope and waterlogged areas in the landscape.

Aquifer uses: Minor use, mainly for stock and domestic purposes.

Salinity

Groundwater salinity: Generally in the range of 3000 mg/l to 10000 mg/l.

Salt store: High.

Salinity occurrence: Broad valley floor, drainage lines, small springs.

Soil Salinity Rating: S2, some S3.

Salt export: Both baseflow to streams and wash-off from surface.

Salt impacts: Both on-site and off-site.

Risk

Soil salinity hazard: High.

Water salinity hazard: High.

Major assets at risk: Barwon River, Leigh River, Moorabool River, Woady Yaloak Creek, Ramsar Wetlands, urban water supplies (Geelong and Ballarat), engineering and urban infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be moderate to high.

Management Options

Biological control measures will potentially reduce recharge to the groundwater system proper, but can be very effective in reducing lateral flow through the upper regolith which will reduce the discharge 'load' accumulating on the flats. By removing this 'fresh' component, the area affected by saline discharge can be reduced in size. However, moderate to high rainfall limits the effectiveness of perennial pasture in recharge control, and soil fertility and acidity issues restrict the use of lucerne. This may leave a role for native grasses, although the recharge benefit has yet to be quantified. Provided they fit into the farming system, trees should aid by intercepting lateral flow on the undulating granite slopes, and reducing recharge to the fractured rock aquifer system on the upper slopes and crests.

Groundwater pumping is unviable due to the low permeability, deeply weathered landscape. Waterlogging control on the slopes may be assisted by surface and sub-surface drainage, but the economics and the downstream impact are problematic.

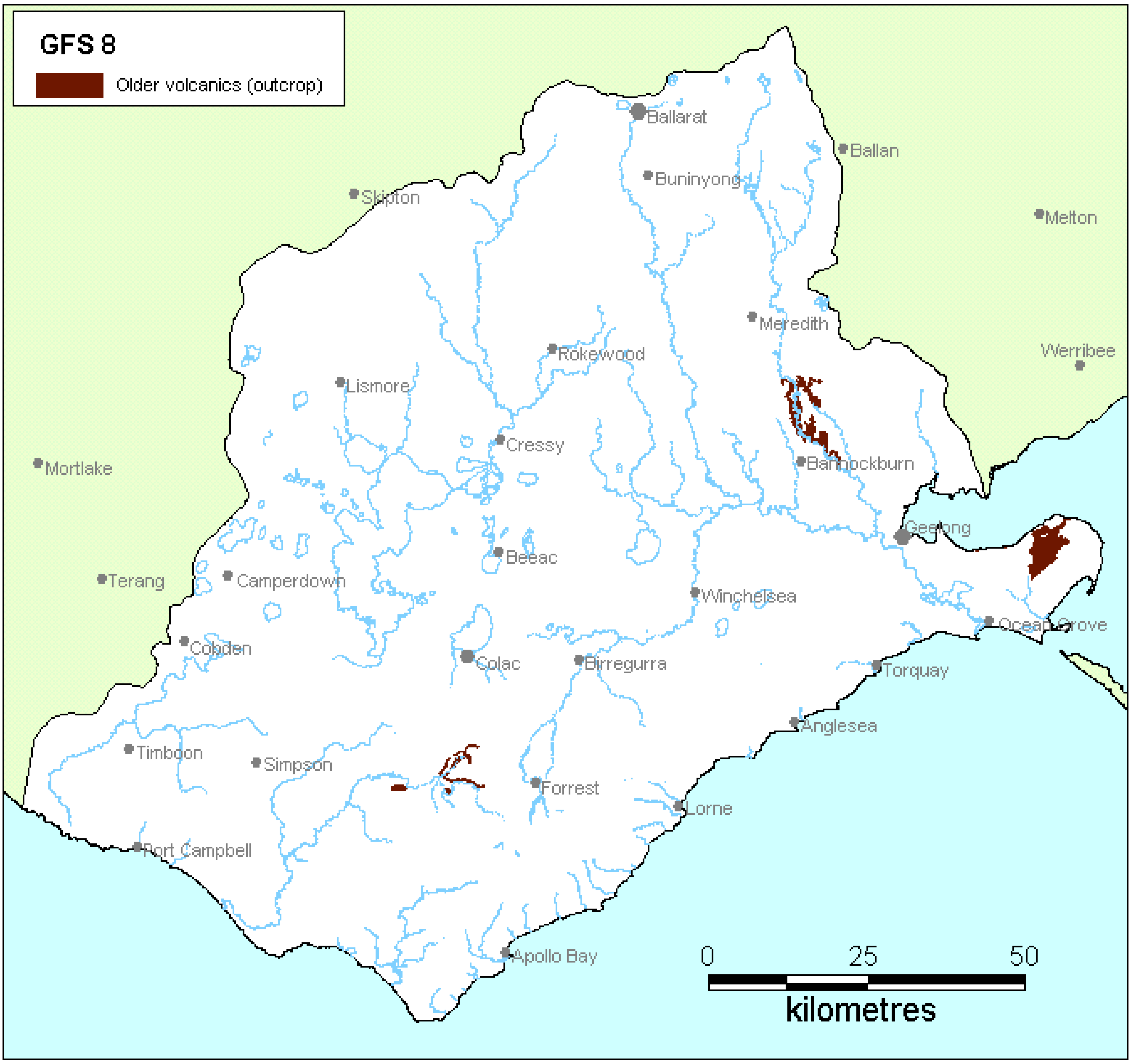
Despite the localised nature of many of the flow cells, a significant treatment strategy will revolve around treatment of the broad valley flats as biological and engineering solutions are limited in their practical scope.

At Lismore control of drainage line salinisation is dependent upon limiting recharge entering the veneer of basalt and Pliocene sands sitting on obscured granite. In practical terms change of this nature is difficult to achieve, so that dealing with creek line degradation is likely to be the highest priority.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Comments**
Local flow systems in (Palaeozoic) granites	Biological Management of recharge	Perennial pastures	Low to moderate – suitable in local systems below 700mm annual rainfall. Doubtful value in treating intermediate flow systems
		Crop management	N/a
		Trees/woody vegetation	Low to moderate – Break of slope plantings in local flow systems, doubtful benefits in intermediate systems
	Engineering intervention	Surface drainage	Moderate to high – Reduction of surface waterlogging and consequent salinity impacts in local flow systems.
		Groundwater pumping	Low – low permeability landscapes
	Productive uses of saline land and water	Salt tolerant pastures	Moderate to high – Salt and water logging tolerant grasses
		Halophytic vegetation	Low – Poorly suited to climate
		Saline aquaculture	Low – Poor aquifer capacity and difficult to extract groundwater
		Salt harvesting	Low – Groundwater insufficiently saline
		Others	See OPUS database (NDSP)

Local and Intermediate Flow Systems in the Older Volcanics



S2 and S3 salinity in the Pliocene Sands at the edge of the Older Volcanics, Yarram Creek, Bellarine Peninsula. This salinity may be due to groundwater discharge at the boundary of the adjacent Older Volcanics.

Local and Intermediate Flow Systems in the Older Volcanics

Region: South and eastern CCMA (Western Victorian Plains and Southern Uplands)

Type areas: Bellarine Peninsula, Lower Moorabool River Valley, Kawarren

Description: The Older Volcanics were formed by sporadic volcanism during the Palaeogene (early Tertiary) and outcrop on the Bellarine Peninsula, the lower Moorabool River valley and in locally in the Gellibrand and Kawarren region (Yaugher Volcanics). In most places the fractured, basalt rocks have undergone extensive weathering, resulting in thick clay soils at the surface, except in the Gellibrand region, where the volcanics comprise gravel-sized volcaniclastic sandstone. The subsurface extent of this GFS may be greater than its extent in outcrop. Although occurrences are not connected, Older Volcanics have been intersected in bores around Cressy, Eastern View (Angahook basalt), Maude (Maude basalt) and at depths of over 850 metres around Cooriemungle.

Groundwater moves in intermediate flow systems at depth through the fractures in the basalt and in local flow systems through the weathered rock and soil. Groundwater quality is generally good, and is the source of natural mineral water at Clifton Springs. Although salinity discharge is not mapped in the Older Volcanics GFS, extensive saline discharge occurs around the edges at Yarram Creek on the Bellarine Peninsula. The provenance of this groundwater discharge may be the adjacent Older Volcanics, which should be further investigated.

Landscape attributes

Geology: Older Volcanics (Pvo)

Topography: Low hills and valley slopes.

Land Systems:

3.0 Southern Uplands
- *3.3 Dissected low hills*
  - 3.3.1 Plateau
  - 3.3.2 Rolling hills

6.0 Western Plains
- *6.1 Volcanic plains*
  - 6.1.4 Plains with well developed drainage

Regolith: Clay soils and deeply weathered rock.

Annual rainfall: 500 to 900 mm.

Dominant mid-1800s vegetation type: Woodland and forest

Current dominant land uses: Grazing, cropping, conservation.

Mapping method: Outcrop geology and estimated sub-crop.

Hydrogeology

Aquifer type (porosity): Fractured rock and saprock (secondary porosity); Volcaniclastic sediments, saprolite and clay soil (primary porosity).

Aquifer type (conditions): Unconfined to semi confined. Confined at depth.

Hydraulic Conductivity (lateral permeability): Unknown. Probable range 10^{-6} m/d to 10^{-2} m/d.

Aquifer Transmissivity: Unknown. Probably less than 20 m^2/d.

Aquifer Storativity: Unknown. Probably less than 0.05.

Hydraulic gradient: Unknown. Probably moderate to locally steep in valleys.

Flow length: Unknown. Probably ranges from less than one kilometre to a maximum of ten kilometres.

Catchment size: Small for local systems (<10 Ha); intermediate systems probably depend on cross-formational flow.

Recharge estimate: Unknown, but would vary with location.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Unknown. Catchment wide in outcrop, with contributions from cross-formation flow at depth.

Aquifer uses: Some stock and domestic use. The Mineral Springs at Clifton Springs discharge from the Older Volcanics.

Salinity

Groundwater salinity: Generally in the range of 1500 mg/l to 3000 mg/l.

Salt store: Low to moderate.

Salinity occurrence: None within this GFS. The salinity that occurs in the Pliocene Sand (GFS 10) on the Bellarine Peninsula may be attributed to the discharge at the boundary of the Older Volcanics.

Soil Salinity Rating: Low

Salt export: Low (if any)

Salt impacts: Unknown, may contribute to saline discharge into Yarram Creek.

Risk

Soil salinity hazard: Low

Water salinity hazard: Low

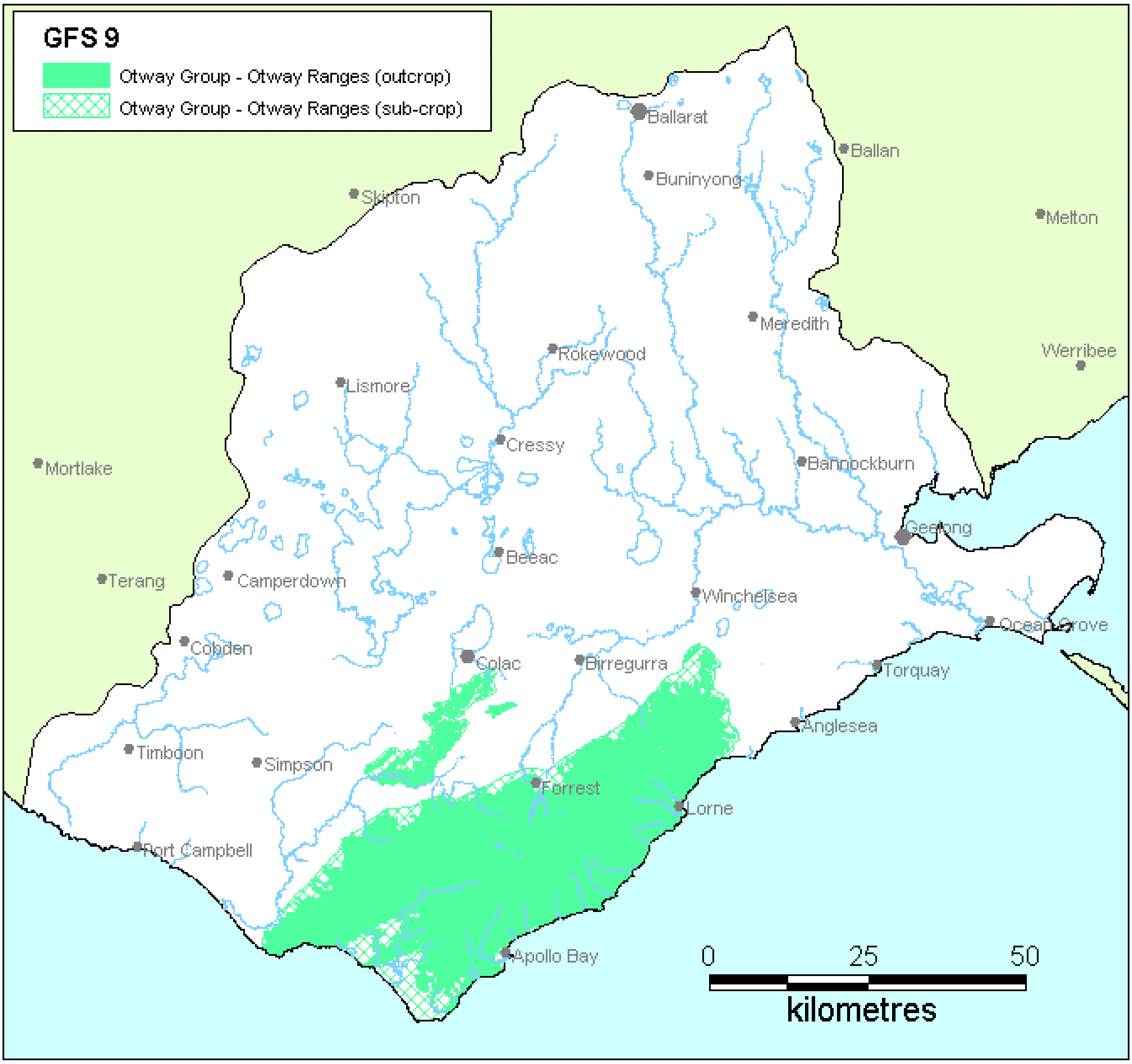
Major assets at risk: Moorabool, Barwon and Gellibrand rivers, urban water supply (Geelong), engineering infrastructure, agricultural land, conservation areas, Mineral Springs (Clifton Springs).

Responsiveness to land management: Unknown.

Management Options

Generally not a salinity problem. However further investigation of the role this GFS plays (if any) to the salinity at Yarram Creek needs investigation.

Local and Intermediate Flow Systems in the Otway Group Rocks (Otway Ranges)



Cutting showing fractured sandstone and soil cover at Morley Avenue, Wye River

Local and Intermediate Flow Systems in the Otway Group Rocks (Otway Ranges)

Region: Southern CCMA (Southern Victoria Uplands)

Type areas: Wye River, Beech Forest, Forest, Lavers Hill

Description: The lithic sandstone and mudstone rocks that make up the Otway Ranges were formed from sediments deposited in a rift valley between Australia and Antarctica during the Cretaceous period. The continued uplift and erosion of the Otway Ranges since the Miocene has created deeply dissected landscapes with thin soils. The majority of the catchment is forested, with a significant proportion of public land.

Groundwater flows through the fractured rocks in intermediate and local flow systems, recharged by the high rainfall. The groundwater discharge into the streams of the Otway Ranges contributes to urban and farm water supplies, including those utilising the Barwon and Gellibrand Rivers, and groundwater contamination from urban (mostly coastal) development and nutrients may be an emerging threat to water quality. Current knowledge suggests that this GFS does not contribute to the salinity problem.

Landscape attributes

Geology: Otway Group – Eumeralla Formation (Kl)

Topography: Ridges and steep valleys.

Land Systems:

<u>3.0 South Uplands</u>

- *3.1 Deeply-dissected upland*
  - 3.1.1 Plateau
  - 3.1.2 Dissected ranges
  - 3.1.4 Alluvial terraces and floodplains

Regolith: Skeletal to gradational soils over moderately weathered sedimentary rocks

Annual rainfall: 900 to 1900 mm

Dominant mid-1800s vegetation type: Forest, rainforest

Current dominant land uses: Conservation, water supply, forestry, grazing, dairying, tourism.

Mapping method: Outcrop and estimated sub-crop distribution.

Groundwater discharge at The Boulevard, Wye River

Hydrogeology

Aquifer type (porosity): Fractured rock (secondary porosity)

Aquifer type (conditions): Unconfined to semi-confined

Hydraulic Conductivity (lateral permeability): Largely unknown. Estimated range from 10^{-4} m/d to 10^{1} m/d.

Aquifer Transmissivity: Generally less than 1000 m^2/d.

Aquifer Storativity: Estimated range from 0.02 to 0.1.

Hydraulic gradient: Generally moderate but can be locally very steep in valleys.

Flow length: Estimated <2 km for local systems up to 15 km for intermediate systems.

Catchment size: Estimated to be <20000 Ha.

Recharge estimate: Unknown. Possibly 200 mm/yr or more.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: General catchment wide, with less on steeper slopes.

Aquifer uses: Minor stock and domestic use.

Salinity

Groundwater salinity: Fresh. Generally less than 1500mg/l.

Salt store: Low

Salinity occurrence: None known.

Soil Salinity Rating: Low (Nil).

Salt export: None known.

Salt impacts: None known.

Risk

Soil salinity hazard: Nil.

Water salinity hazard: Nil.

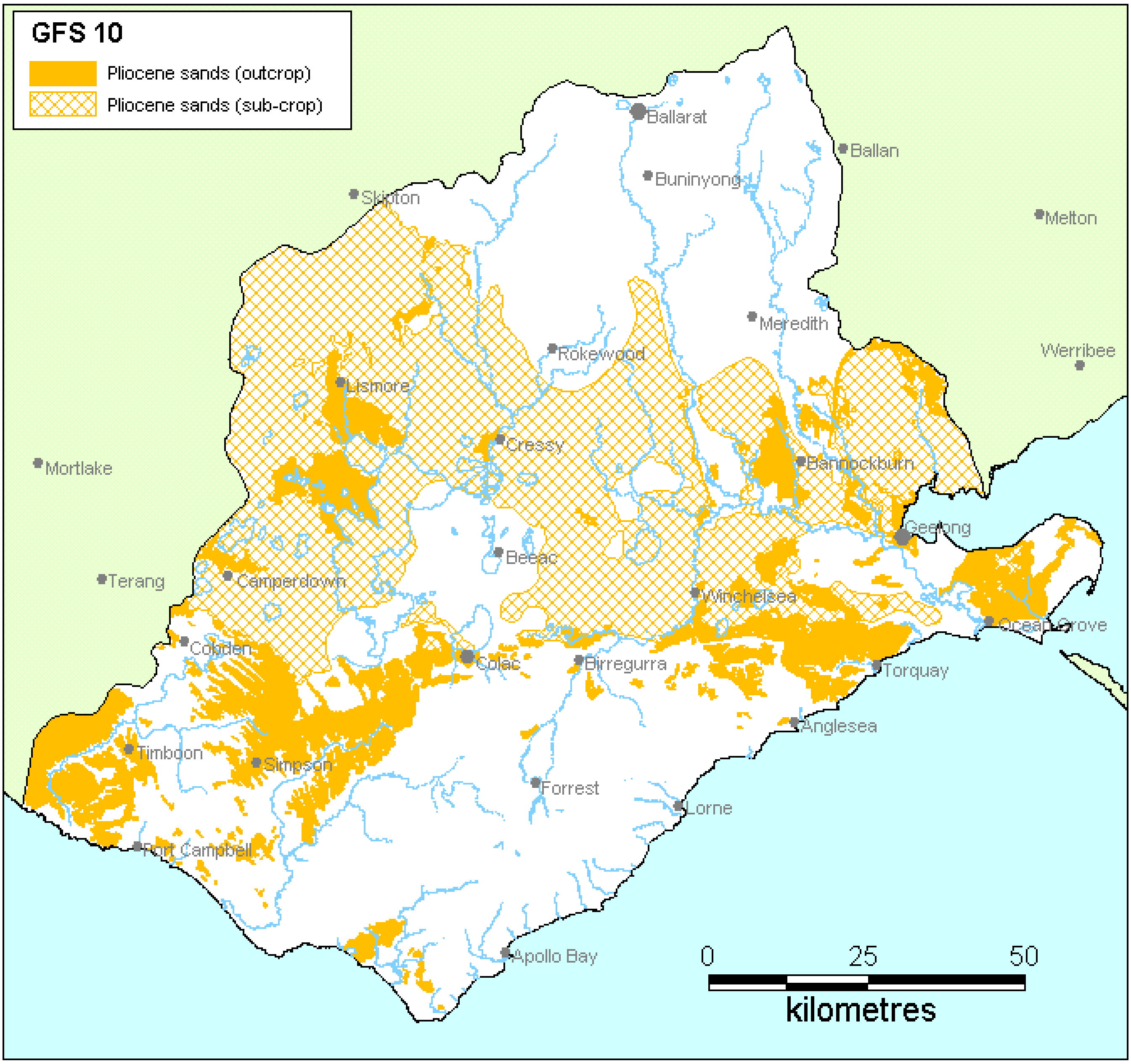
Major assets at risk: Nil

Responsiveness to land management: Unknown, and not applicable to salinity management.

Management Options

Not a salinity problem. Management should be directed at maintaining water quality and protection from contamination.

Intermediate and Local Flow Systems in Pliocene sands



Shallow saline lake in the Pliocene Sand, Homestead Road, Leslie Manor.

Intermediate and Local Flow Systems in Pliocene sands

Region: Central and southern CCMA region (Western Victorian Plains)

Type areas: Duck Hole Plain, Leslie Manor, Lismore, Bellarine Peninsula

Description: In the Pliocene, a shallow sea covered nearly the entire CCMA region. As the sea retreated, a thin veneer of gravels, sands, silts and clays were deposited over the landscape. In places the sand sheet has been ferruginised or silicified and it is mostly covered by the volcanic rocks (GFS 14).

This flow system has a broad geographical and morphological range. In the Western Plains, groundwater generally moves slowly under low gradients through the partially exposed sheets of Pliocene sands in intermediate flow systems. The local flow systems occur where the sand forms isolated caps on dissected ridges, especially in the Heytesbury. Discrete local flow systems also occur on the Bellarine Peninsula and south of the Barrabool Hills.

Landscape attributes

Geology: Hanson Plain Sand and Moorabool Viaduct Formation and equivalents (Npb).

Topography: Plains and low hills, dissected coastal plain; palaeo-strand lines; outcrops of sub-basaltic sheet, shallow lakes and wetlands.

Land Systems:

- <u>3.0 Southern Uplands</u>
  - *3.3 Dissected low hills*
    - 3.3.2 Rolling hills
- <u>6.0 Western Plains</u>
  - *6.1 Volcanic Plains*
    - 6.1.3 Plains with poorly developed drainage
    - 6.1.4 Plains with well developed drainage
  - *6.2 Sedimentary plains*
    - 6.2.2 Dissected plains
    - 6.2.4 Plains and plains with low rises

Regolith: Sands, gravel, silt, clay, ferruginised sands, ironstone gravels, podsol soils (‘coffee rock’), occasional silcrete,

Annual rainfall: 450 to 900 mm

Dominant mid-1800s vegetation type: Shrubland, woodland, heathland.

Current dominant land uses: Dairying, grazing, cropping, conservation.

Mapping method: Outcrop geology and estimated sub-crop distribution.

Hydrogeology

Aquifer type (porosity): Gravels to fine sands, silts and clays (primary porosity), ferruginised or silicified rock (secondary porosity).

Aquifer type (conditions): Unconfined, semi-unconfined to confined

Hydraulic Conductivity (lateral permeability): Variable and largely unknown. Probably from 10^{-2} m/d to 10 m/d.

Aquifer Transmissivity: Variable, but generally in the moderate range. Estimated to be generally less than 20 m^2/d.

Aquifer Storativity: Variable. Estimated to be from 0.05 to 0.10.

Hydraulic gradient: Estimated to be very low (0.0001) in intermediate systems on the plains to moderate (0.01) in local systems. Could be locally steep at the edges of the Pliocene sand caps on dissected ridges.

Flow length: Unknown. Possibly up to 50km in intermediate systems to a few metres in local systems.

Catchment size: Estimated to vary from very small (<1 Ha) in local systems to moderate (>1000 Ha) in intermediate systems.

Recharge estimate: Highly variable depending on location and aquifer position.

Temporal distribution of recharge: Seasonal (winter and spring) where exposed at the surface, with significantly more recharge in wetter years. May be continual steady recharge where overlain by volcanics.

Spatial distribution of recharge: Catchment wide on outcrops and extensive leakage from overlying basalt (GFS 14) and stony rises (GFS 2) on the plains.

Aquifer uses: Minor stock and domestic use.

Salinity

Groundwater salinity: Generally in the range of 1000 mg/l to 10000 mg/l.

Salt store: Moderate to High.

Salinity occurrence: Drainage depressions (including lakes, swamps), some flat areas adjacent to basalt boundaries, and top of granites at Lismore.

Soil Salinity Rating: S2 to S3.

Salt export: Wash off from surface and base flow discharge to lakes and rivers.

Salt impacts: Both on-site and off-site

Risk

Soil salinity hazard: Moderate to High (scalding).

Water salinity hazard: Moderate.

Major assets at risk: Ramsar Wetlands, Barwon River, Leigh River, Moorabool River, Woady Yaloak Creek, urban water supplies (Geelong and Ballarat), engineering and urban infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be high for local systems and low for intermediate systems.

Management Options

Discharge in the local flow systems of the Heytesbury region often occurs as elevated springs at the base of the thin remnant sand caps. These springs are an integral process of landscape evolution by providing a mechanism for landslides. Even though landslides occurred before the forest was cleared, they have dramatically increased since. The rafting of sands downslope by the landslides has been identified as creating a salinity problem in the Heytesbury marls (GFS 4). Massive revegetating of the ridges (which is the only biologically feasible option) will reduce but not eliminate the process; and in practical terms is highly doubtful given the economics and commensurate benefits of such plantings. Current economics as well as off-site drainage considerations are likely to render engineering solutions as unfeasible.

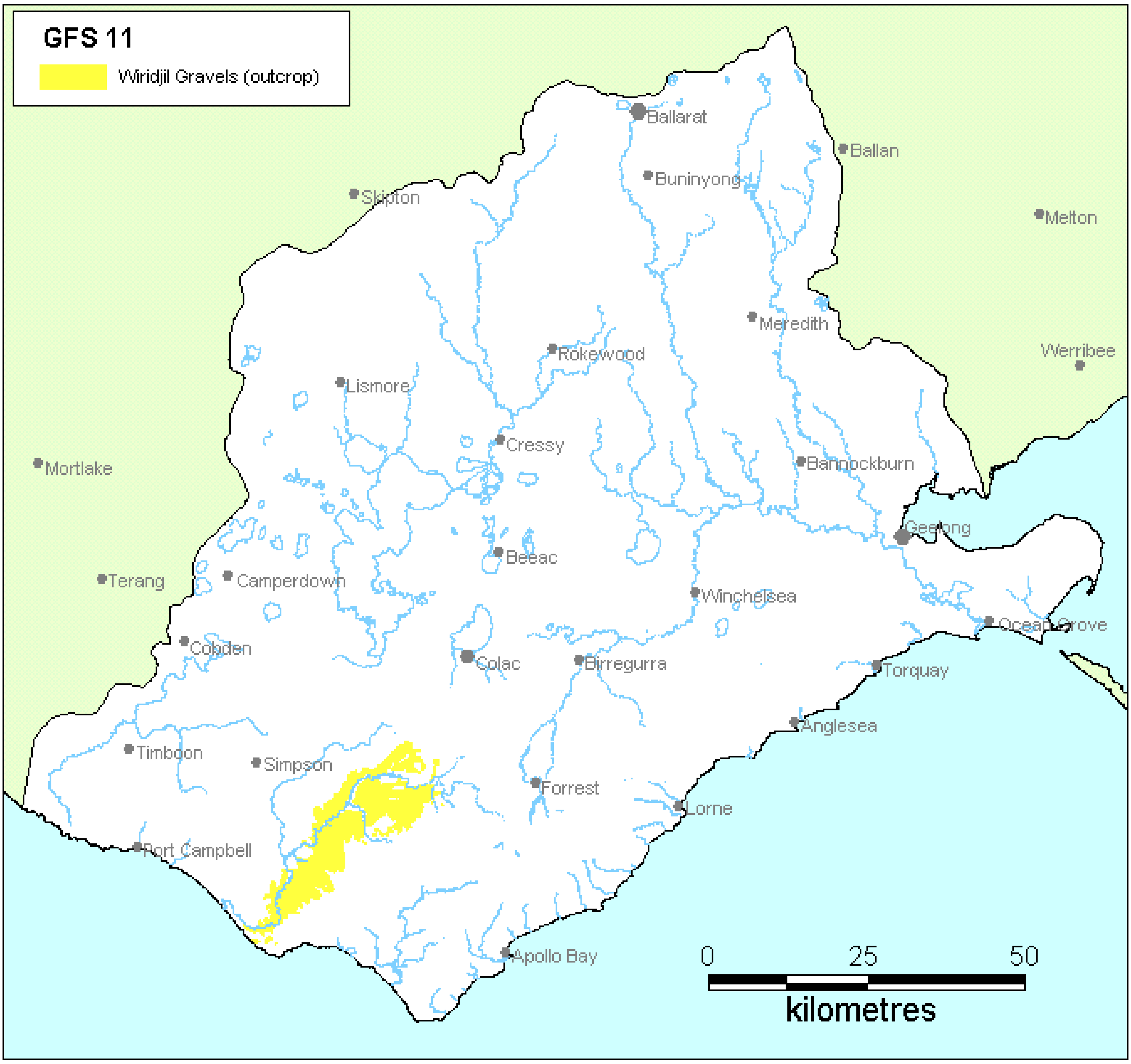
The intermediate flow systems in the sheet sands would require broadscale recharge control to generate any significant impacts. A significant proportion of the sand sheet is recharged from leakage of water through the overlying volcanic rock, and any recharge control effort would also be required across the basalt plains. In terms of agriculture, biodiversity and economics, this would be undesirable, impractical and uneconomic. In addition, the system would be slow to respond, especially given the low hydraulic gradients. In particular with saline discharge (i) on the western of Lake Corangamite (Leslie Manor) and (ii) associated with the Lismore granites the most feasible option probably lies with saline agronomy opportunities.

Where the sand sheets are isolated, biological options for recharge control are more practical, for example in the heavily salinised Thompsons Creek and Yarram Creek catchments. However, given the rainfall, broadscale perennial woody vegetation rather than pastures is likely to be more successful.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Comments**
Intermediate and local flow systems in Pliocene sands	Biological Management of recharge	Perennial pastures	Low to moderate – Suitable below 700mm rainfall, but salinity benefits dependant on scale of flow system
		Crop management	Low to moderate – Potential for inter-cropping with lucerne
		Trees/woody vegetation	Low to moderate – May be some local instances where plantations can be used as interceptors
	Engineering intervention	Surface drainage	Low – little opportunity to intercept recharge
		Groundwater pumping	Moderate to high – Where high value assets are to be protected
	Productive uses of saline land and water	Salt tolerant pastures	Moderate – Salt tolerant grasses, existing technologies
		Halophytic vegetation	Low – Poorly suited to climate
		Saline aquaculture	Moderate – May be feasible where used in concert with asset protection, but issues of salt and nutrient management need consideration
		Salt harvesting	Low – Groundwater not sufficiently saline
		Others	See OPUS database (NDSP)

Intermediate and Local Flow Systems in the Wiridjil Gravel and equivalents



Region: South western CCMA region (Southern Uplands)

Type areas: Carlisle River, Chapple Vale, Devondale

Description: This GFS combines the geological units of the Wiridjil Gravel and Moomowroong Sand into one flow system based on assumed similar hydrogeological character and the lack of known salinity problems. Although very similar to the regional flow system of the Dilwyn Formation (GFS 17), this flow system differs in that it is not implicated in any salinity processes. Based on very few bores and the little information available, it is believed that groundwater flows in intermediate and local flow systems and provides fresh baseflow discharge to the Gellibrand River.

Landscape attributes

Geology: Moomowroong Sand and Wiridjil Gravel (Pan)

Topography: Hills and valleys, low sandy hills.

Intermediate and Local Flow Systems in the Wiridjil Gravel and equivalents

Landscape attributes (cont.)

Land Systems: 3.0 Southern Uplands; *3.3 Dissected low hills*

Regolith: Sandy soils, gravels, sands, sometimes ferruginised.

Annual rainfall: approximately 1100 mm

Dominant mid-1800s vegetation type: Forest and woodland

Current dominant land uses: Grazing, dairying, water supply,

Mapping method: Outcrop.

Hydrogeology

Aquifer type (porosity): Gravel, sand, silt and clay (primary porosity)

Aquifer type (conditions): Unconfined.

Hydraulic Conductivity (lateral permeability): Estimated from 10^{-2} m/d to 10^{2} m/d

Aquifer Transmissivity: Generally less than 1000 m^2/d.

Aquifer Storativity: Estimated range from 0.05 to 0.2.

Hydraulic gradient: Generally moderate to low.

Flow length: Estimated from up to 10 km.

Catchment size: Estimated to be <10000 Ha.

Recharge estimate: Unknown, possibly quite high (~200^{+} mm/yr?)

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Catchment wide.

Aquifer uses: Very little, if any.

Salinity

Groundwater salinity: <1500 mg/l.

Salt store: Low

Salinity occurrence: None known

Soil Salinity Rating: None known

Salt export: None known.

Salt impacts: None known.

Salinity Risk

Soil salinity hazard: None known.

Water salinity hazard: None known.

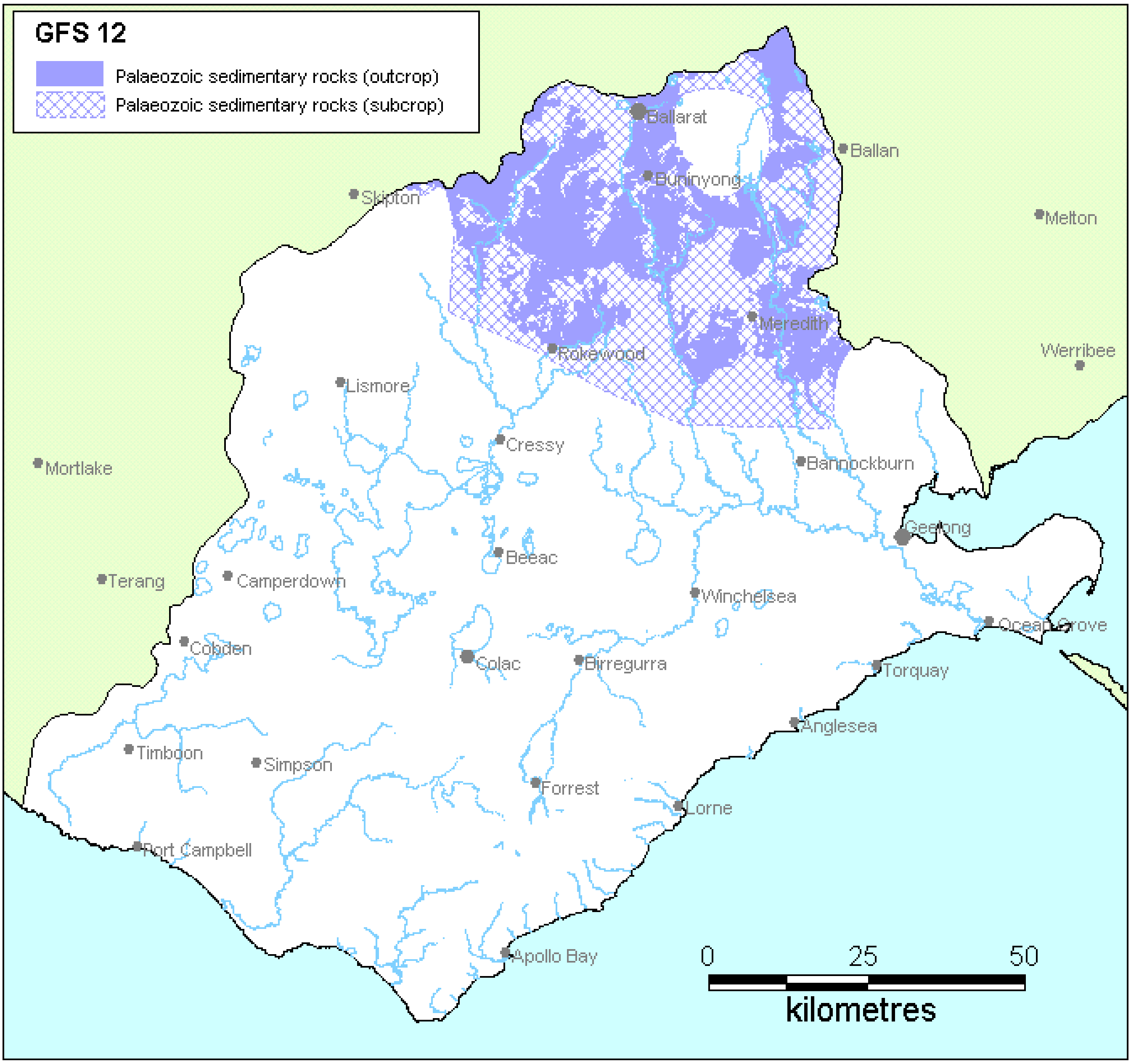
Major assets at risk: Unknown.

Responsiveness to land management: Unknown

Management Options

This GFS has no known salinity problems or groundwater management issues.

Intermediate and Local Flow Systems in Palaeozoic sedimentary rocks



S2 and S3 soil salinity on the Mt Mercer – Dereel Road, Mt Mercer.

Intermediate and Local Flow Systems in Palaeozoic sedimentary rocks

Region: Northern CCMA region uplands (Western Victorian Uplands)

Type areas: Cape Clear, Dereel, Linton, Mt Helen

Description: The sedimentary rocks in the northern part of the CCMA region were formed around 500 million years ago during the Palaeozoic era. Since their formation they have been folded and faulted, injected with quartz veins and intruded by granites. Extensive erosion has removed several kilometres thickness of material and the exposed rocks are deeply weathered. They are covered by an uneven thickness of weathered rock and soil.

Groundwater slowly moves through the fractured rocks and regolith in both local and intermediate flow systems. On the basis of response in similar GFS elsewhere in south east Australia, this GFS should respond well to salinity management options.

Landscape attributes

Geology: Shale, sandstone, mudstone, slate and quartz veins. Cambrian and Ordovician age turbidite sediments of the St Arnaud Group (Es) and Castlemaine Supergroup (Ol, Oll, Olm).

Topography: Undulating hills, broad valleys, can be locally steep.

Land Systems:

<u>2.0 Western Uplands</u>

2.1 Dissected uplands.

2.1.1 Ridges, plateaux, hills and valley slopes underlain by Palaeozoic sedimentary and metamorphic rock (including greenstone).

Regolith: Variable deeply weathered profile (soil, saprolite, saprock to fresh rock).

Annual rainfall: 600 to 800 mm.

Dominant mid-1800s vegetation type: Forest.

Current dominant land uses: Grazing, forestry, urban (Ballarat), conservation.

Mapping method: Outcrop geology and estimated sub-crop

Hydrogeology

Aquifer type (porosity): Fractured rock and saprolite (secondary porosity).

Aquifer type (conditions): Unconfined and semi confined.

Hydraulic Conductivity (lateral permeability): Highly variable. The saprolite varies from approximately 10^{-5} m/d to 10^{-1} m/d and the rock varies from 10^{-5} m/d (measured at Ballarat) to 1 m/d.

Aquifer Transmissivity: Highly variable in the low to moderate range. Estimated to be generally less than 50 m^2/d.

Aquifer Storativity: Variable. Estimated to be less than 0.03 for saprolite and 0.02 to 0.05 for the fractured rock.

Hydraulic gradient: Estimated to be moderate in intermediate systems and locally steep in local systems.

Flow length: Generally <25 km for intermediate systems and <5 km for local systems.

Catchment size: Small (~<500 Ha) for local systems and moderate (>100 km^2) for intermediate systems.

Recharge estimate: Approximately 40 mm to 50 mm annually.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years.

Spatial distribution of recharge: Catchment wide but varies with the depth of regolith, slope and wet areas in the landscape.

Aquifer uses: Minor use, mainly for stock and domestic purposes.

Salinity

Groundwater salinity: Generally in the range of 1000 mg/l to 8000 mg/l.

Salt store: Moderate to high.

Salinity occurrence: Valley floor, break-of-slope, hillside seeps.

Soil Salinity Rating: S2 to S3.

Salt export: Both baseflow to streams and wash-off from surface.

Salt impacts: Both on-site and off-site.

Risk

Soil salinity hazard: High.

Water salinity hazard: Very high.

Major assets at risk: Barwon River, Leigh River, Moorabool River, Woady Yaloak Creek, Ramsar Wetlands, urban water supplies (Geelong and Ballarat), engineering and urban infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be moderate for intermediate flow systems and high for local flow systems.

Management Options

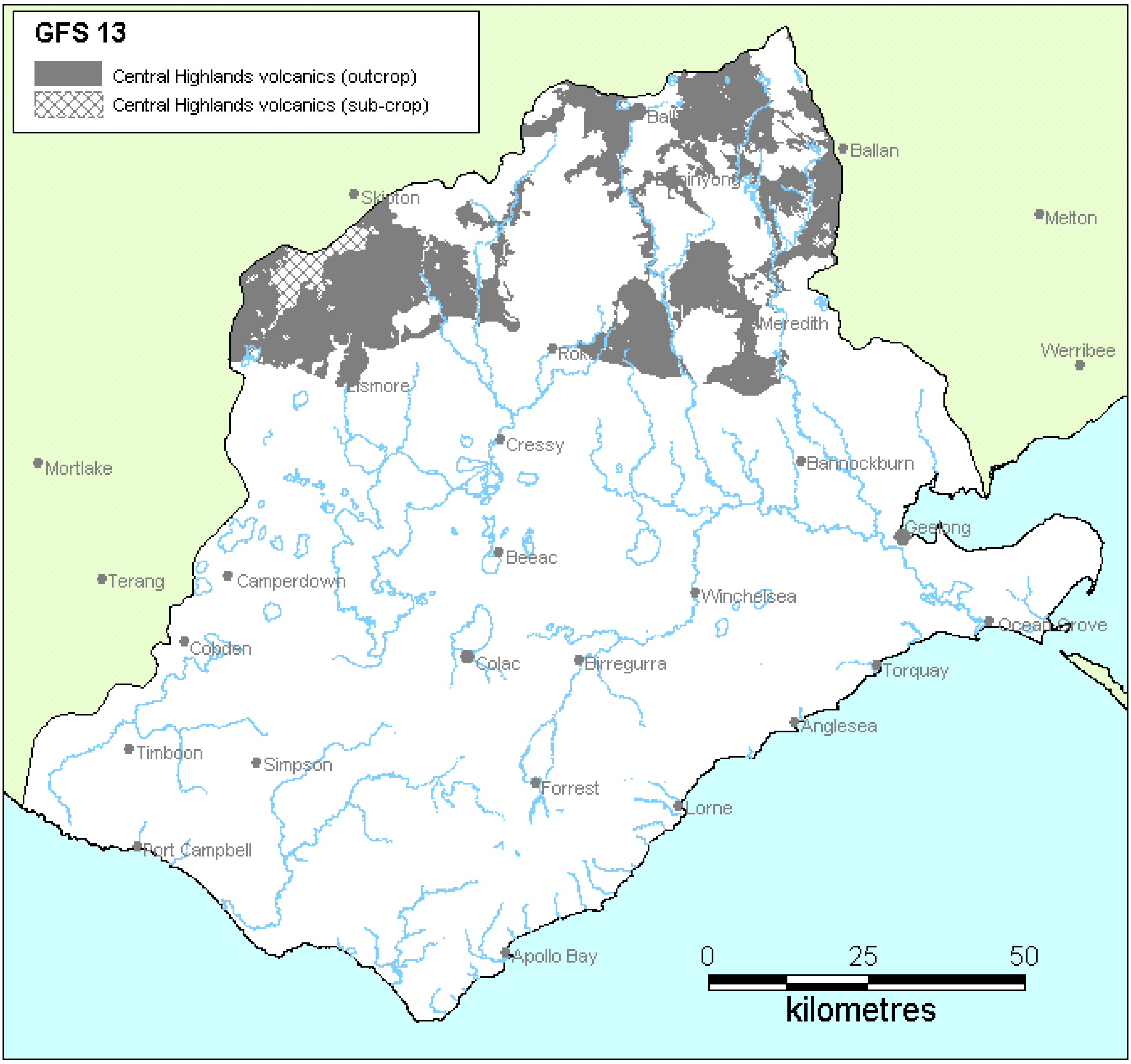
The varied land-use, ranging from grazing, farm forestry, mining and quarrying, conservation to urban development (around Ballarat) is a significant challenge for salinity management within this GFS. These represent a spectrum of asset managers with different concerns and priorities. Apart from the obvious impacts of land salinisation, water quality is arguably the most vital asset to be protected, both from the perspective of river health as well as urban water supply (i.e. drainage from the sedimentary hills feeds the water supply reservoirs for Ballarat and the Barwon River system).

Optimal salinity management outcomes can be expected with localised groundwater flow cells in areas where the regolith is thin. With regards to recharge control, the effectiveness of perennial pastures is doubtful owing to high rainfall. Trees are viable if they are able to fit into the farming system; as happens with the expanding farm forestry industry in the Mt. Mercer - Dereel area. Engineering solutions such as groundwater pumping are not suitable for broad-scale application owing to the heterogeneity of fractured rock systems, but may be worth investigating if there is a discrete localised asset at risk. Engineering options within this GFS, however, are unlikely to be viable for sustaining the health of a river system such as the Barwon.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Comments**
Intermediate and local groundwater flow systems in Palaeozoic sedimentary rocks	Biological Management of recharge	Perennial pastures	Low to moderate – Limited by high rainfall and responsiveness give n scale of groundwater flow
		Crop management	N/a
		Trees/woody vegetation	High for local systems - Planting over fractured rock outcrops in responsive aquifers Low to Moderate for intermediate systems – limited salinity benefit in the longer term.
	Engineering intervention	Surface drainage	Low – Very limited opportunity to intercept surface water to prevent recharge
		Groundwater pumping	Moderate – Where high value assets demand protection
	Productive uses of saline land and water	Salt tolerant pastures	Moderate to high – Salt tolerant grasses with existing technologies
		Halophytic vegetation	Low - Unsuitable climate
		Saline aquaculture	Moderate – Technically feasible, providing salt and nutrients can be managed.
		Salt harvesting	Low – Groundwater not saline enough
		Others	See OPUS database (NDSP)

Intermediate and Regional Flow Systems in the Central Highlands volcanic rocks



S2 and S3 soil salinity, Sebastopol – Smythesdale Rd, Ross Creek.
The Deep Lead below (GFS 15) is evident by the mine mullock dump on the horizon.

Intermediate and Regional Flow Systems in the Central Highlands volcanic rocks

Region: Northern CCMA region uplands (Western Uplands)

Type areas: Ballarat, Mt Mercer, Woady Yaloak

Description: The basalt rocks in the northern part of the CCMA region were formed by volcanic eruptions between 6 million and 2 million years ago when lava flows filled the pre-existing deep river valleys and then spilled out across the landscape. The fractured, fine-grained crystalline rocks have rapidly weathered, forming a blanket of clay soil of variable thickness.

Groundwater moves through the fractured rocks at highly variable rates. Some recharge may occur through the scoria cones (GFS 2, eg. Mt Buninyong, Hardies Hill and Mt Warrenheip) and some leakage may occur to the underlying Deep Lead GFS (GFS 15). . Around the northern edge of the CCMA catchment at Ballarat, some of the groundwater flows north into the Murray Basin, even though the surface water flows south. The groundwater resource is a major asset for irrigation of summer crops (eg. potatoes) around Bungaree, Wallace and Pootilla. Saline discharge occurs along drainage lines around Ross Creek, Haddon and Elaine.

Landscape attributes

Geology: Newer Volcanics basalt (Qvn) of Neogene and Quaternary age.

Topography: Undulating plains and low rises.

Land Systems:

2.0 Western Uplands

2.1 Dissected Uplands

2.1.4 Volcanic landforms, including plains, plateaux, valley flows, scoria cones, and lava shields.

Regolith: Heavy clay soil and weathered rock of variable thickness.

Annual rainfall: 600 to 900 mm.

Dominant mid-1800s vegetation type: Woodlands and grasslands.

Current dominant land uses: Cropping, grazing, urban, conservation.

Mapping method: Outcrop geology and estimated sub-crop.

Hydrogeology

Aquifer type (porosity): Fractured rock (secondary porosity), soil (primary porosity).

Aquifer type (conditions): Unconfined and semi confined.

Hydraulic Conductivity (lateral permeability): Extremely variable. The rock varies from 10^{-3} m/d (tight fractures) to 10^{2} m/d (open fractures), soil varies from 10^{-6} m/d (heavy clays) to 10^{-2} m/d (thin clayey loams).

Aquifer Transmissivity: Highly variable in the moderate to high range. Estimated to be generally less 50 m^2/d to 200 m^2/d.

Aquifer Storativity: Variable. Estimated to be <0.03 to >0.05 for the fractured rock.

Hydraulic gradient: Estimated to be low (0.001) in intermediate systems and very low (0.0001) in regional systems.

Flow length: Generally less than 10 kilometres for intermediate systems and greater than 50 kilometres along basalt-filled ancient river valleys for regional systems.

Catchment size: Small to medium for both regional and intermediate systems.

Recharge estimate: Unknown, but thought to be up to 50 mm annually.

Temporal distribution of recharge: Seasonal (winter and spring), with significantly more recharge in wetter years, when extensive soil waterlogging can occur.

Spatial distribution of recharge: Catchment wide but varies with the soil thickness, slope and waterlogged areas in the landscape. More recharge can occur through where overlain by scoria cones (GFS 2).

Aquifer uses: Significant use for irrigation, stock and domestic purposes.

Salinity

Groundwater salinity: Generally in the range of 1000 mg/l to 10000 mg/l.

Salt store: Moderate.

Salinity occurrence: Swamps, drainage lines, broad depressions in the landscape, boundaries of basalt flows.

Soil Salinity Rating: S2 and S3.

Salt export: Both baseflow to streams and wash-off from surface.

Salt impacts: Both on-site and off-site.

Risk

Soil salinity hazard: Variable. Generally low, but may vary with age of soil development, since it is high in some areas.

Water salinity hazard: High in catchments where saline discharge occurs.

Major assets at risk: Barwon River, Leigh River, Moorabool River, Woady Yaloak Creek, urban water supplies (Geelong and Ballarat), groundwater supplies, engineering infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be slow.

Management Options

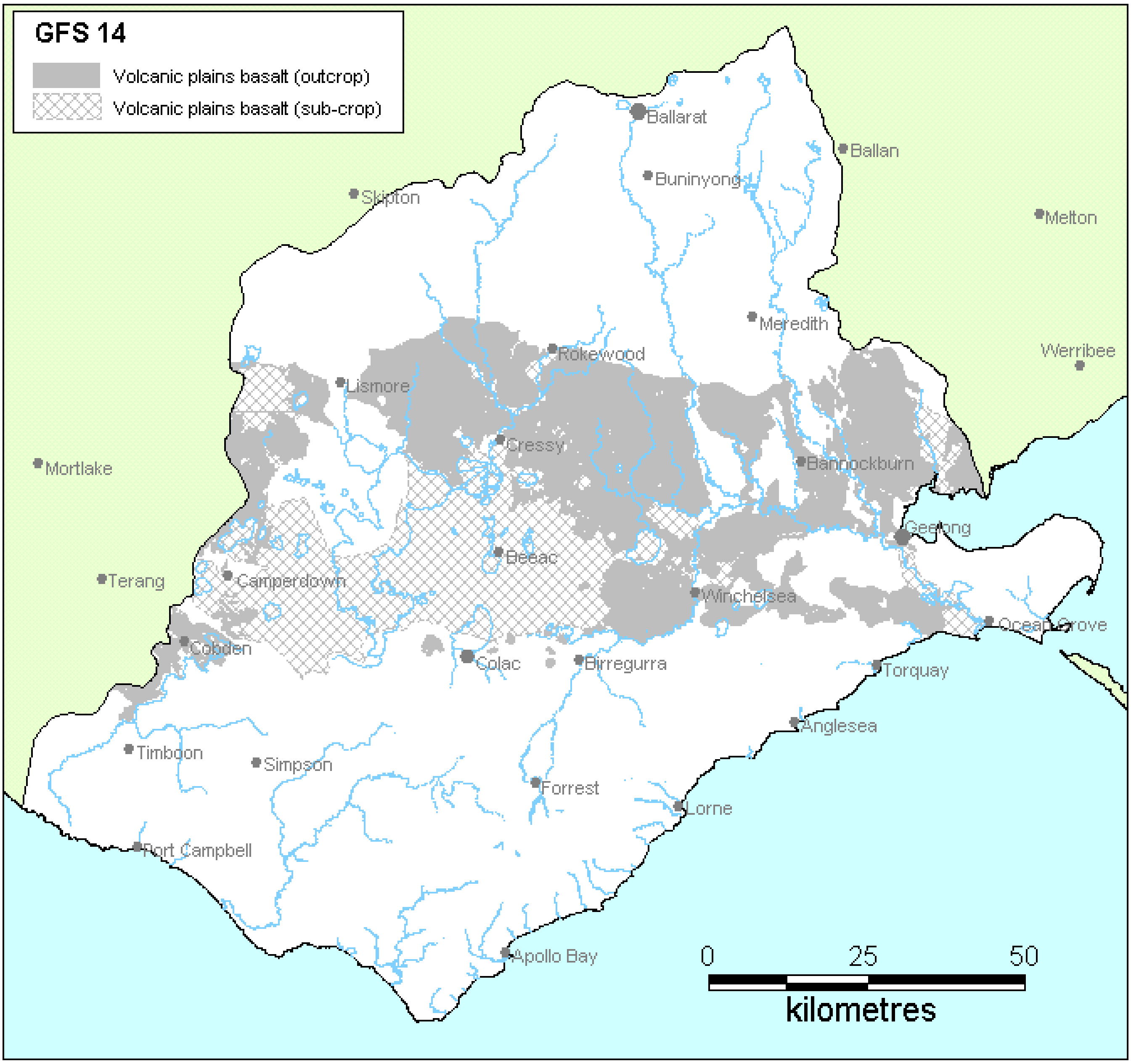
Given the assumed slow response of recharge control in intermediate and regional groundwater flow systems and the fact that salinity management options need to be balanced with the protection of groundwater assets in high value agricultural land, regionally reducing watertables is not a practicable option, be it by biological or engineering means. Perennial pasture and woody vegetation (especially within the bounds of existing agricultural systems) are unlikely to achieve significant result in terms of salinity benefit.

Logically, it would be more appropriate to target discharge management in the reasonably limited number of catchments where saline discharge occurs. However, there is growing evidence that natural seasonal ponding of surface waters in ephemeral depressions and wetlands may aid in 'freshening' the landscape, at the same time limiting the exposure of underlying brackish watertables that would otherwise lead to localised soil salt accumulation. It is possible that surface drainage of low lying areas may actually increase the salinity hazard. The limited ability to control recharge means that treatment of saline areas assumes particular importance, be it through revised surface water management strategies (potentially), sowing productive species that are waterlogging and salt tolerant, or rehabilitating wetlands to restore their indigenous ecologies.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Ranking**
Intermediate and regional flow systems in Central Highlands volcanic rocks	Biological Management of recharge	Perennial pastures	Low – Slow response and the need to protect recharge for groundwater asset. Also insufficient evidence of salinity driven by changes in the water balance post-agricultural development
		Crop management	
		Trees/woody vegetation	
	Engineering intervention	Surface drainage	Low – May even exacerbate salinity issues by altering the hydrologic balance of the valley floors
		Groundwater pumping	Moderate – Where high value assets are to be protected
	Productive uses of saline land and water	Salt tolerant pastures	High – Salt tolerant grasses
		Halophytic vegetation	Low – Poor suitability to climate
		Saline aquaculture	Moderate – Technically feasible, particularly in combination with groundwater extraction for asset protection
		Salt harvesting	Low – Groundwater is not saline enough
		Others	See OPUS database (NDSP)

Regional and Intermediate Flow Systems in the Volcanic Plains basalt



S2 and S3 soil salinity, Colac-Ballarat Rd, Werneth

Regional and Intermediate Flow Systems in the Volcanic Plains basalt

Region: Central CCMA region plains (Western Plains)

Type areas: Cressy, Wingeel

Description: The basalt rocks in the central part of the CCMA region were formed by volcanic eruptions between 6 million and 60 thousand years ago. The lava flowed over the pre-existing landscape, following drainage lines and spilling out across the recently formed coastal plains. The fractured, fine-grained crystalline rocks have rapidly weathered, forming a blanket of clay soil of variable thickness.

Groundwater moves through the fractured rocks at highly variable rates in both regional and intermediate flow systems. Research to date has established a strong connection between the surface water bodies and the groundwater system. Saline groundwater discharges in lakes, streams, swamps, and over broad depressions in the landscape.

Of all the CCMA flow systems, the salinity problem statement is no more contentious than on the basalt plains. It is generally acknowledged that the pre-agricultural basalt plains were inherently 'wet' landscapes given the existence of many shallow lakes and wetlands, the climate and the grasslands (possibly shrubland) and/or open woodland. Primary salinity may have been a widespread feature, as ‘salt’ was a descriptive adjective for many of the lakes and creeks in early historical records. However, given the lack of documented hydrological change and impact across the plains, an understanding of the connection between European settlement and salinisation is yet to be explored.

Expert opinion suggests that the plains naturally operated under conditions of seasonal wetlands and soil waterlogging (and accompanying low grade salinity?), and with brackish to saline baseflow into incised stream systems. An emerging hypothesis is that surface water management may be a key to salinity processes on the basalt plains. Natural seasonal ponding of surface waters in ephemeral depressions and wetlands may aid in 'freshening' the landscape, at the same time limiting the exposure of underlying brackish watertables that would otherwise lead to localised soil salt accumulation.

Landscape attributes

Geology: Newer Volcanics basalt (Qvn) of Neogene and Quaternary age.

Topography: Undulating plains and low rises.

Land Systems:

6.0 Western Plains

6.1 Volcanic plains

6.1 3 Plains with poorly developed drainage

6.1.4 Plains with well developed drainage

Regolith: Heavy clay soil and weathered rock of variable thickness.

Annual rainfall: 450 to 600 mm

Dominant mid-1800s vegetation type: Grassland and open woodland (dominant); forest (along the southern fringe).

Current dominant land uses: Cropping, grazing, horticulture, urban, conservation

Mapping method: Outcrop geology and estimated sub-crop

Hydrogeology

Aquifer type (porosity): Fractured rock (secondary porosity), soil (primary porosity).

Aquifer type (conditions): Unconfined and semi confined.

Hydraulic Conductivity (lateral permeability): Extremely variable. The rock varies from 10^{-3} m/d (tight fractures) to 10^{2} m/d (open fracture and lava tubes); soil varies from 10^{-6} m/d (heavy clay) to 10^{-2} m/d (clayey loams).

Aquifer Transmissivity: Highly variable in the moderate to high range. Estimated to be generally less 50 m^2/d to 200 m^2/d.

Aquifer Storativity: Variable. Estimated to be <0.03 to >0.05 for the fractured rock.

Hydraulic gradient: Estimated to be very low (0.0001) in regional systems and low (0.001) in intermediate systems.

Flow length: Generally <50 km for regional systems and <10 km for intermediate systems.

Catchment size: Very large (>500000 Ha) for regional systems and large (>50000 Ha) for intermediate systems.

Recharge estimate: Unknown, but thought to be between 10 mm and 25 mm annually.

Temporal distribution of recharge: Seasonal (winter and spring), with significantly more recharge in wetter years, when extensive soil waterlogging can occur.

Spatial distribution of recharge: Catchment wide but varies with the soil thickness, slope and waterlogged areas in the landscape. More recharge can occur through where overlain by stony rises (GFS 2).

Aquifer uses: Significant use for stock and domestic purposes, some irrigation.

Salinity

Groundwater salinity: Generally in the range of 2000 mg/l to 10000 mg/l.

Salt store: Moderate.

Salinity occurrence: Lakes, swamps, drainage lines, broad depressions in the landscape, boundaries of basalt flows.

Soil Salinity Rating: S2 and S3.

Salt export: Both baseflow to streams and wash-off from surface.

Salt impacts: Both on-site and off-site.

Risk

Soil salinity hazard: Uncertain, but thought to be high in some areas.

Water salinity hazard: High.

Major assets at risk: Ramsar Wetlands, Barwon River, Leigh River, Moorabool River, Woady Yaloak Creek, urban water supplies (Geelong and Ballarat), engineering and urban infrastructure, conservation areas, agricultural land.

Responsiveness to land management: Largely unknown, but thought to be slow.

Management Options

The basalt plains GFS arguably contains the highest value assets in the CCMA – biodiversity assets of international importance, prime agricultural land, major urban and transport infrastructure, surface water and groundwater resources and significant cultural heritage sites. The management of Ramsar other wetlands of international importance (eg. those subject to migratory bird treaties) is of paramount importance. Any manipulation of the groundwater system will need to consider the impact on these surface water bodies.

However, an implication of the assumed intrinsic hydrology of the plains and the slow response times for intermediate to regional groundwater flow systems is that regionally reducing watertables is not a practical or feasible option, be it by biological or engineering means. The realistic question is how to best deal with a naturally saturated landscape underlain by a brackish to saline shallow regional groundwater system.

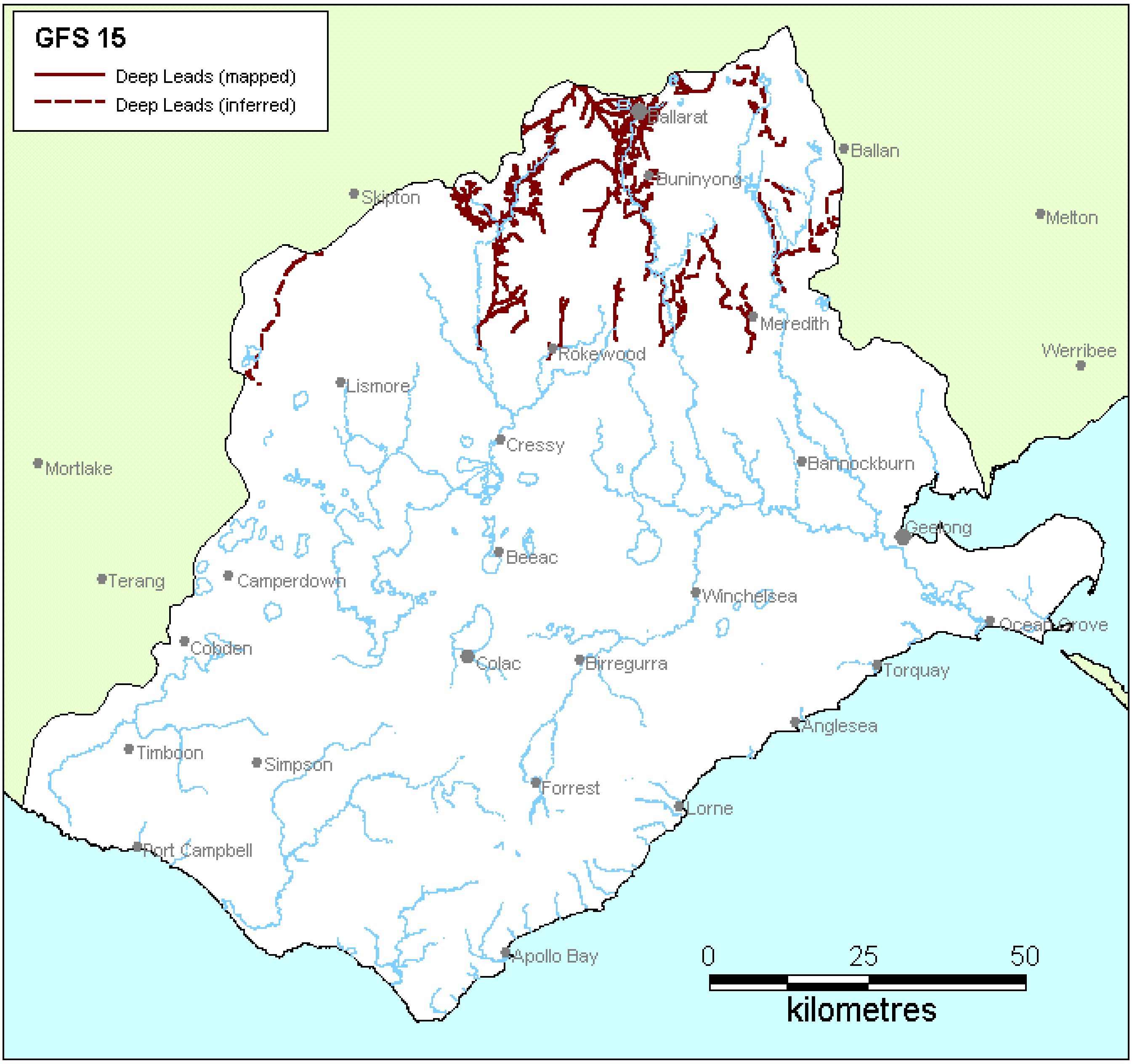
Perennial pasture and woody vegetation (especially within the bounds of existing agricultural systems) are unlikely to achieve a significant result in terms of salinity benefit. In some situations, surface drainage of low-lying areas may actually increase the salinity hazard. Where there are significant assets at risk it is likely that engineering intervention will be the prime consideration.

The limited ability to control recharge means that treatment of saline areas assumes particular importance, be it through revised surface water management strategies (potentially), sowing productive species that are waterlogging and salt tolerant, or rehabilitating wetlands to restore their indigenous ecologies.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Ranking**
Regional flow systems in the Volcanic Plains basalt	Biological Management of recharge	Perennial pastures	Low – Insufficient evidence of salinity driven by changes in the water balance effected by increased recharge post agricultural development
		Crop management	
		Trees/woody vegetation	
	Engineering intervention	Surface drainage	Low – May even exacerbate salinity issues by altering the hydrologic balance of the valley floors
		Groundwater pumping	Moderate – Where high value assets are to be protected
	Productive uses of saline land and water	Salt tolerant pastures	High – Salt tolerant grasses
		Halophytic vegetation	Low – Poor suitability to climate
		Saline aquaculture	Moderate – Technically feasible, particularly in combination with groundwater extraction for asset protection
		Salt harvesting	Low – Groundwater is not saline enough
		Others	See OPUS database (NDSP)

Regional and Intermediate Flow Systems in the subsurface Deep Leads



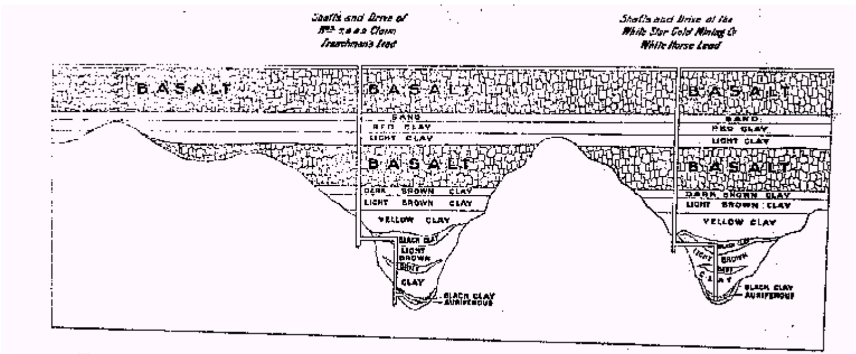


Fig. 8. Cross section of Frenchman's and White Horse Leads, Ballarat. By J. Wall. Scales: Horizontal, 12 chains to 1 inch; vertical, 150 chains to 1 inch.

Cross-section through two Deep Leads at Ballarat, showing the river valleys buried by the lava flows (basalt rock) from volcanic eruptions about 2 million years ago. Groundwater flows along the gravels of the ancient river beds.
Diagram from:
BARAGWANATH, W. 1923. The Ballarat Gold-field. *Memoir* **14**. Geological Survey of Victoria. p. 16.

Regional and Intermediate Flow Systems in the subsurface Deep Leads

Region: Northern CCMA (Western Uplands)

Type areas: Woady Yaloak, Pitfield Plains

Description: Deep Leads are ancient river valleys buried by volcanic lava flows or the build up of sediments (or both). They include the ancient Yarowee, Moorabool and Woady Yaloak, rivers and their tributaries. They were a valuable source of gold in the early mining history of the region and most have been extensively mined.

High volumes of groundwater flow south along the buried river alluvium (gravel, sand, silt and clay) except around Ballarat, where some of the ancient rivers flowed north into the Murray Basin. Control of the water flow through the buried river deposits was a considerable problem for the early gold miners. The influence of these regional groundwater flow systems on salinity in the CCMA region is unknown, as little is understood about the hydraulics of deep lead pressures and how these pressures are dispersed beneath the basalt plains south of Rokewood and/or north of Ballarat. There is, however, a hypothesis that some salinity outbreaks mapped at the hills - plains interface may be a function of reducing hydraulic gradients in these systems.

As the deep lead systems are high flow regional groundwater systems, groundwater salinity and salt store is generally only expected to be moderate. The key salinity impact is likely to be caused by elevated baseflow occurring in interbasaltic streams. However, the exact impact of these systems on the salinisation of land and water resources is best described as uncertain.

Landscape attributes

Geology: Deep Leads (Calivil Formation equivalent).

Topography: Subsurface buried river valleys.

Land Systems:

Subsurface in 2.0 Western Uplands	Subsurface in 6.0 Western Uplands
2.1 Dissected Uplands	*6.1 Volcanic plains*

Regolith: Not applicable.

Annual rainfall: 600 to 750 mm at recharge areas.

Dominant mid-1800s vegetation type: Not applicable.

Current dominant land uses: Resource used as water supply.

Mapping method: Estimated subsurface distribution.

Hydrogeology

Aquifer type (porosity): Gravel, sand, silt and clay (primary porosity)

Aquifer type (conditions): Confined, may outcrop at headwaters.

Hydraulic Conductivity (lateral permeability): Largely unknown. Estimated range from 10^{-2} m/d to 10^{2} m/d.

Aquifer Transmissivity: Generally less than 1000 m^2/d.

Aquifer Storativity: Estimated range from 0.05 to 0.2.

Hydraulic gradient: Generally low to very low.

Flow length: Estimated up to 30 km.

Catchment size: Estimated to be <20000 Ha.

Recharge estimate: Unknown.

Temporal distribution of recharge: Unknown. Probably marginally seasonal (winter and spring), with more recharge in wetter years, but may be relatively even leakage through overlying basalt and sediment throughout the year.

Spatial distribution of recharge: General leakage from overlying Newer Volcanics (GFS 13, GFS 2) and Quaternary sediments (GFS 1).

Aquifer uses: Irrigation, stock and domestic use.

Salinity

Groundwater salinity: Unknown. Probably in the range of 200 mg/l to 3000 mg/l.

Salt store: Low.

Salinity occurrence: Unconfirmed discharge on basalt plains (GFS 14).

Soil Salinity Rating: Unknown.

Salt export: Unknown. Possible baseflow to streams.

Salt impacts: Unknown. Possible off-site (baseflow and surface salinity).

Risk

Soil salinity hazard: Unknown. Potentially a risk to Basalt Plains salinity.

Water salinity hazard: Unknown. Potentially a risk to Basalt Plains salinity.

Major assets at risk: Unknown (if any)

Responsiveness to land management: Unknown

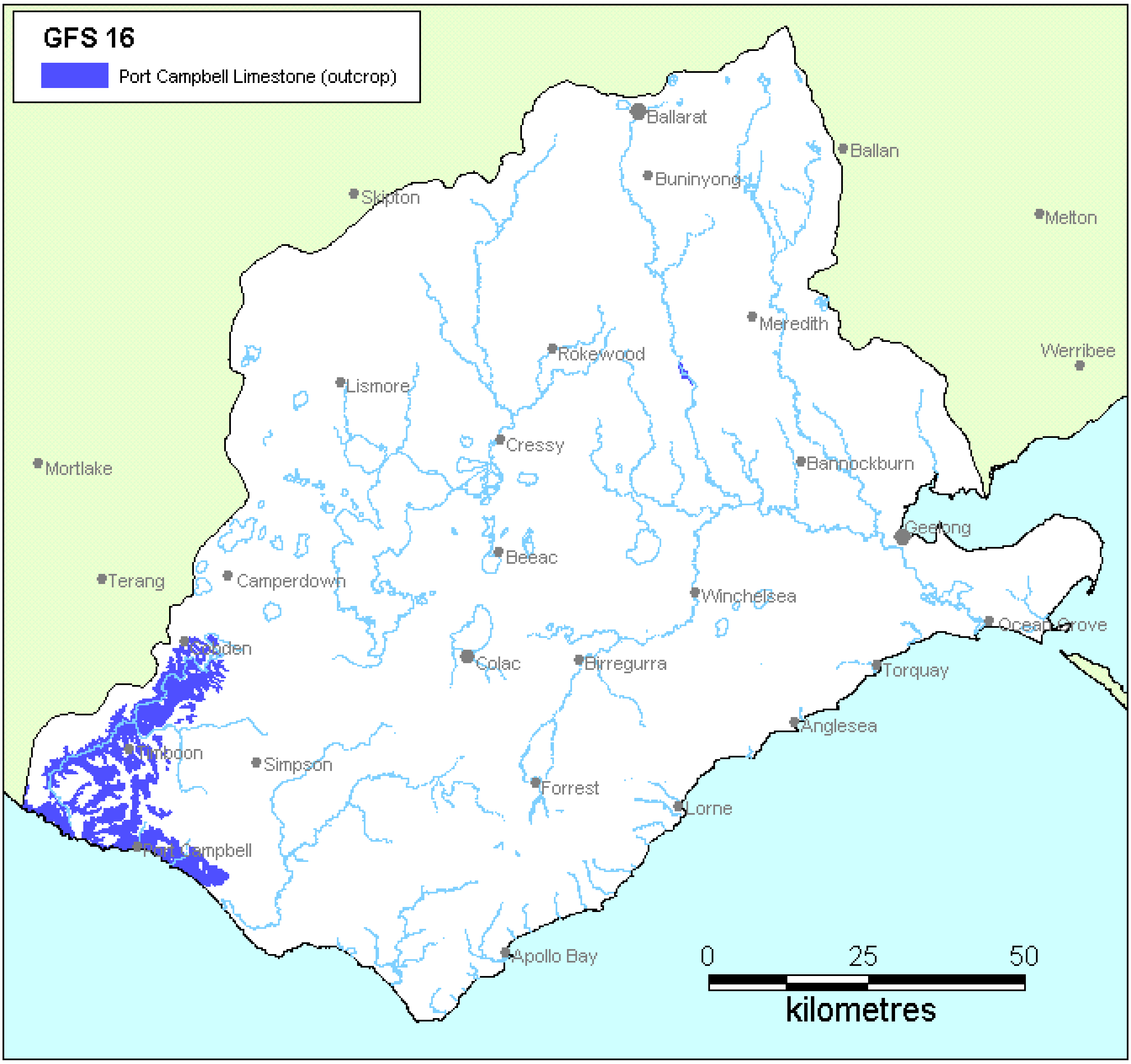
Management Options

As these systems are usually recharged from overlying flow systems the ability to control recharge is substantially reduced. However, given the system permeability and throughflow, groundwater pumping presents a significant opportunity for both alleviating groundwater pressures and providing supply opportunities. As the link between deep leads and surface salinisation is tenuous there is little reason to comment on saline agronomy opportunities.

Options for Managing Dryland Salinity within Groundwater Flow Systems in the Corangamite CMA Region

Groundwater Flow System	**Options**	**Treatments**	**Comments**
Regional flow systems in the subsurface Deep Leads	Biological Management of recharge	Perennial pastures	Low – Scale of system is too large to be responsive
		Crop management	As above
		Trees/woody vegetation	As above
	Engineering intervention	Surface drainage	As above
		Groundwater pumping	Moderate to high – If required to protect major assets, or where groundwater can be extracted as a resource
	Productive uses of saline land and water	Salt tolerant pastures	Moderate to high – Salt tolerant grasses (if and when salinity is identified as an issue)
		Halophytic vegetation	Low – Poorly suited to climate
		Saline aquaculture	Moderate to high – Potential for saline & non saline aquaculture providing salinity and nutrients can be managed
		Salt harvesting	Low – Salinity of groundwater too low
		Others	See OPUS database (NDSP)

Regional Flow Systems in the Port Campbell Limestone



Region: Southern CCMA (Western Plains)

Type areas: Scott's Creek, Port Campbell

Description: The Port Campbell Limestone was deposited in shallow marine conditions in the Otway Basin during the Neogene (Mid-late Tertiary). The limestone is an important aquifer for water supply and has developed karst features in the far south west. No salinity issues or processes are attributed to this GFS.

Landscape attributes

Geology: Port Campbell Limestone (Nmg)

Topography: Plain with low undulations and minor karst features (sinkholes).

Land Systems: 6.0 Western Plains. *6.2 Sedimentary plains.*

Regolith: Clay soils over moderately weathered limestone.

Regional Flow Systems in the Port Campbell Limestone

Landscape attributes (cont.)

Annual rainfall: 800 to 1000 mm.

Dominant mid-1800s vegetation type: Forest, Heathland (coastal).

Current dominant land uses: Water supply, dairying, grazing, conservation.

Mapping method: Outcrop and estimated sub-surface distribution.

Hydrogeology

Aquifer type (porosity): Fractured and karstic Limestone (secondary porosity)

Aquifer type (conditions): Unconfined to semi confined.

Hydraulic Conductivity (lateral permeability): Estimated range 10^{-2} m/d to 10^{2} m/d.

Aquifer Transmissivity: Generally less than 1000 m^2/d.

Aquifer Storativity: Estimated range from 0.05 to 0.2.

Hydraulic gradient: Generally low to very low.

Flow length: Estimated up to 30 km.

Catchment size: Estimated to be <20000 Ha.

Recharge estimate: Unknown.

Temporal distribution of recharge: Probably marginally seasonal (winter and spring).

Spatial distribution of recharge: Outcrop and leakage from overlying Pliocene sands.

Aquifer uses: Urban water supply (Port Campbell, Peterborough), irrigation, stock and domestic use.

Salinity

Groundwater salinity: Generally less than 1500 mg/l.

Salt store: Low

Salinity occurrence: None known

Soil Salinity Rating: None known

Salt export: None known.

Salt impacts: Unknown (if any).

Salinity Risk

Soil salinity hazard: Nil.

Water salinity hazard: Nil.

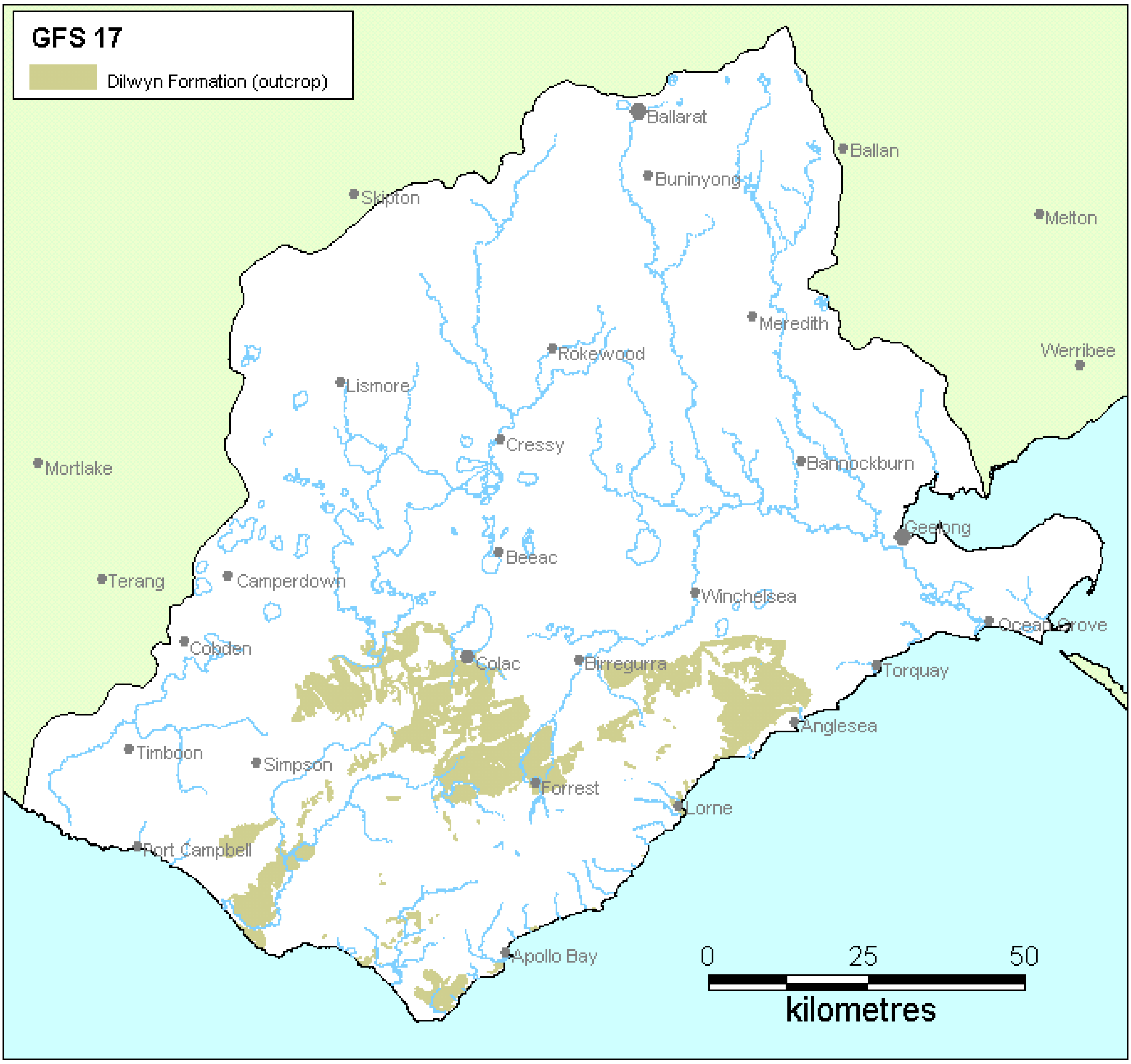
Major assets at risk: Unknown. Used as water supply for towns.

Responsiveness to land management: Unknown

Management Options

No known salinity problems. Groundwater resource management is an issue.

Regional Flow Systems in the Dilwyn Formation



Groundwater Station at Gerangamete supplements Geelong's water supply.

Regional Flow Systems in the Dilwyn Formation

Region: Southern CCMA (Western Victoria Plains)

Type areas: Ferguson's Hill, Barongarook

Description: This GFS combines the geological units of the Dilwyn Formation and the Eastern View Formation, both comprises sandy sediments (gravel, sand, silt and clay) deposited in the Otway Basin during the Palaeogene. In general, the Dilwyn Formation is exposed in outcrop along the northern flanks of the Otway Ranges and the Eastern View Formation is exposed at the north-eastern end of the Otway Range. At depth, this GFS is an important confined aquifer that supplies the City of Geelong.

The potentiometric surface[1] of this GFS is close to the surface, therefore this system influences the overlying local flow systems in the Heytesbury marl (GFS 4) and the Gerangamete marl (GFS 5).

Landscape attributes

Geology: Dilwyn Formation (Pad) and Eastern View Formation (Pae).

Topography: Plain with low sandy hills.

Land Systems: 3.0 Southern Uplands *3.2 Dissected Upland & 3.3 Dissected low hills*

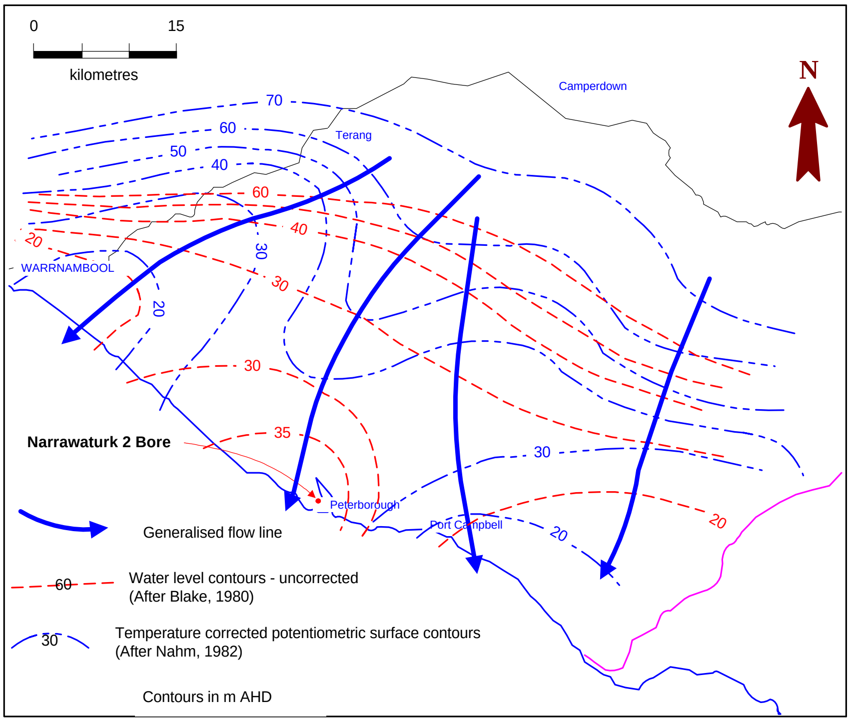
Regolith: Sandy soils, gravels, sands, sometimes ferruginised.

Annual rainfall: 700 to 1100 mm

Dominant mid-1800s vegetation type: Forest, woodland, shrubland, scrub, heathland.

Current dominant land uses: Water supply, water conservation, grazing, dairying.

Mapping method: Outcrop and estimated sub-surface distribution.



Potentiometric surface contours of the Dilwyn Formation in the Heytesbury (J. Leonard, 2002)

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[1] Potentiometric surface is an imaginary surface representing the total head of groundwater and is defined as the level to which water will rise in a tightly cased bore.

Hydrogeology

Aquifer type (porosity): Gravel, sand, silt and clay (primary porosity)

Aquifer type (conditions): Confined at depth, unconfined at outcrop.

Hydraulic Conductivity (lateral permeability): Estimated range 10^{-2} m/d to 10^{2} m/d.

Aquifer Transmissivity: Generally less than 1000 m^2/d.

Aquifer Storativity: Estimated range from 0.05 to 0.2.

Hydraulic gradient: Generally low to very low.

Flow length: Estimated up to 30 km.

Catchment size: Estimated to be <20000 Ha.

Recharge estimate: Unknown.

Temporal distribution of recharge: Unknown. Probably marginally seasonal (winter and spring), with more recharge in wetter years, but may be relatively even throughout the year.

Spatial distribution of recharge: Where outcrop occurs. Some leakage from overlying formations and cross-formational flow.

Aquifer uses: Urban water supply (Geelong), irrigation, stock and domestic use.

Salinity

Groundwater salinity: Fresh, generally less than 1500 mg/l.

Salt store: Low

Salinity occurrence: None known

Soil Salinity Rating: None known

Salt export: Unknown. Possible baseflow to streams.

Salt impacts: Unknown. Supplies head to GFS 4 & GFS 5

Salinity Risk

Soil salinity hazard: Unknown.

Water salinity hazard: Unknown.

Major assets at risk: Unknown. Used as water supply for Geelong.

Responsiveness to land management: Unknown

Management Options

No known salinity problems. Groundwater resource management is an issue.

Appendix A Groundwater Flow System workshop participants

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