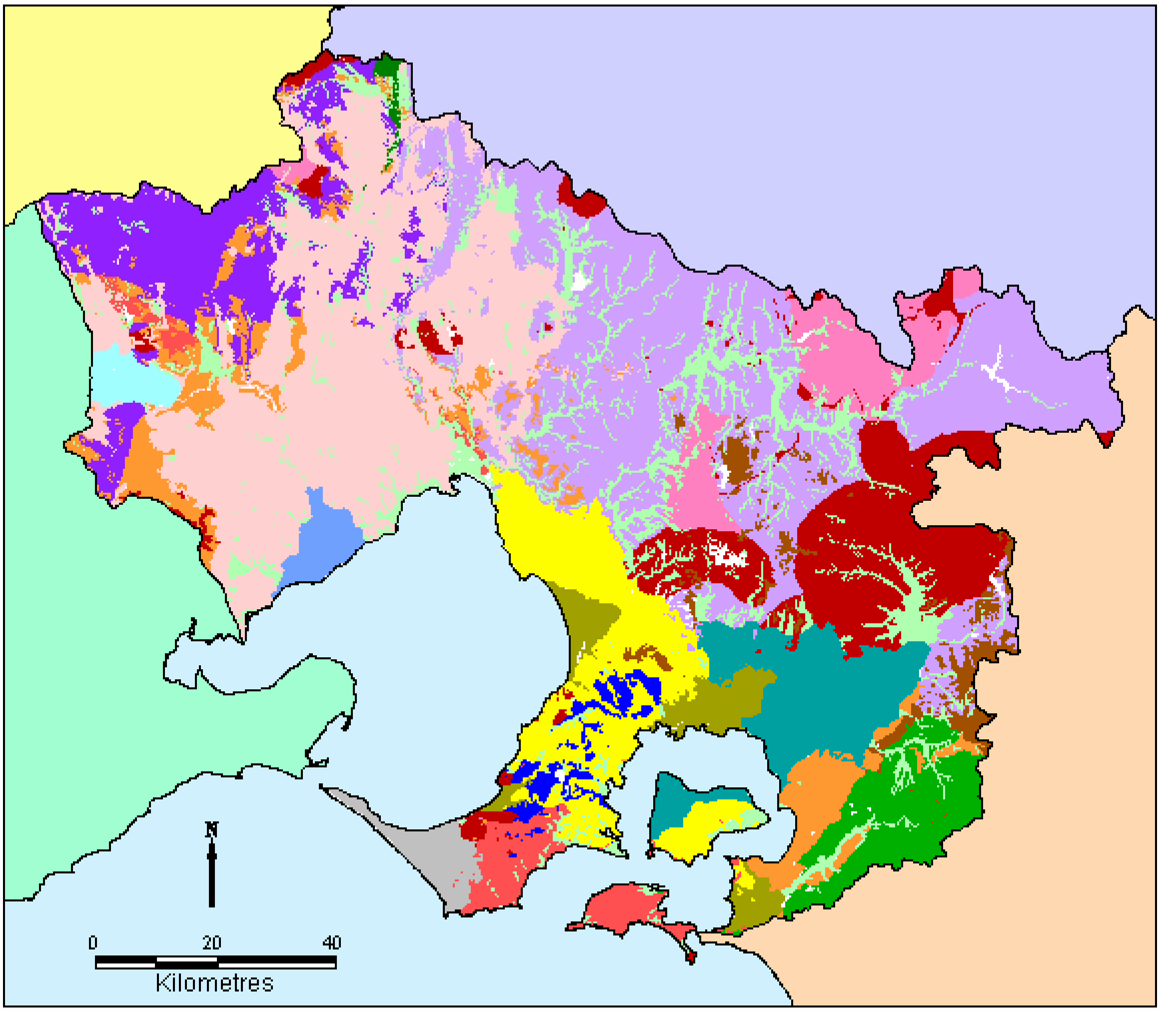
Port Phillip and Westernport

Groundwater Flow Systems



Victoria

Port Phillip and Westernport

CATCHMENT MANAGEMENT AUTHORITY

Cite this document as:Dahlhaus P.G., Heislers D.S., Brewin D., Leonard J.L., Dyson P.R. & Cherry D.P. (2004). Port Phillip and Westernport Groundwater Flow Systems. Port Phillip and Westernport Catchment Management Authority, Melbourne, Victoria.

Authored by Peter Dahlhaus[1], David Heislers[2], Darrell Brewin[3], John Leonard[4], Phil Dyson[5] & Don Cherry[2]

[1] Dahlhaus Environmental Geology Pty Ltd, Buninyong
[2] Primary Industries Research, Victoria, Bendigo
[3]Darrell Brewin and Associates Pty Ltd, Torquay
[4]John Leonard Consulting Services Pty Ltd, Carnegie
[5]Phil Dyson and Associates Pty Ltd, Strathsfieldsaye

for the Port Phillip and Westernport Catchment Management Authority

Published by the Port Phillip and Westernport Catchment Management Authority,

Frankston, Victoria, Australia

www.ppwpcma.vic.gov.au

Port Phillip and Westernport Groundwater Flow Systems.
ISBN: To be confirmed on completion

The Port Phillip and Westernport Catchment Management Authority acknowledge:

- *The Victorian Government for funding this publication through the Department of Sustainability and Environment.*
- *The Department of Primary Industries for organising and coordinating this project. In particular, the efforts of Julie White & Viv Amenta are acknowledged.*
- *The participants of the groundwater flow systems workshop, October 14th to 16th, 2003*

Summary

Eighteen groundwater flow systems have been delineated in the Port Phillip and Westernport Catchment Management Authority region based on the model put forward by the National Land and Water Resources Audit. Of these, 15 are predominately local groundwater flow systems, 2 are predominately intermediate, and one is predominately a regional flow system. Consensus on the flow systems was an outcome of a three-day workshop held in October 2003, 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.

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 (water quality, environmental, agricultural, urban and engineering infrastructure, and cultural and 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 Port Phillip and Westernport CMA region. However, the delineation of groundwater flow systems provides the most current and appropriate framework for the selection of salinity management options, as well as the opportunity to assess the knowledge gaps in the hydrogeology of the region.

Table of Contents

1 Introduction

This report describes the Groundwater Flow Systems (GFS) for the Port Phillip and Westernport Catchment Management Authority (PPWPCMA) region. The groundwater flow systems have been delineated to assist in the development of the PPWPCMA Salinity Management Plan and are the outcome of a three-day workshop held on 14th to 16th October 2004 at Pakenham and Tynong North. Twenty-three invited experts and/or stakeholders in salinity and groundwater issues in the PPWPCMA region (Appendix A) attended the workshop, which was facilitated by Ray Evans, Phil Dyson and Darrel Brewin (all consultants).

The workshop and this report on the PPWPCMA GFS should be regarded as the initial attempt to delineate groundwater flow systems as a useful 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 the first five years of the PPWP Salinity Management Plan. 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. Inevitably, a revision of the GFS will necessitate a reassessment of salinity risk and salinity management priority areas.

Apart from salinity management, the GFS framework also provides a useful disaggregation of the PPWPCMA landscapes for other current projects, such as the wastewater re-use projects at Werribee and Carrum, and the Cardinia Shire salinity management project (Pillai, 2002; SKM, 2003).

1.1 Scope, authorship and sources of information

The majority of the technical information on the flow systems has been compiled from the data and advice provided by the experts at the workshop, with limited verification. The delineation of the groundwater flow systems was largely the work of Peter Dahlhaus, John Leonard and Don Cherry. Detailed description of all of the groundwater flow systems has been compiled by Peter Dahlhaus and John Leonard. David Heislers, Darrell Brewin and Phil Dyson contributed the management options for those GFS in which salinity is an issue. Supplementary editing, modifications and corrections to all sections were contributed by all the authors.

Information on the various groundwater flow systems and their relation to salinity processes is generally scarce. Despite the number of intensive site-specific groundwater investigations that have been conducted throughout the greater Melbourne Metropolitan area, surprisingly little information has been published or is widely available. Most investigations have been undertaken for geotechnical investigations (eg. City Link tunnels) or contaminated site remediation (eg. Coode Island), and very few have been published. The most useful published investigations include those conducted by the past and present State government agencies involved in hydrogeology. However, these are mostly focused on groundwater resource management, and very few have focussed on saline groundwater flow systems. Aquifer parameters are sourced from the few reliably interpreted pumping tests that have been performed, and many are indicative only, being based on ranges for similar rock-types published in hydrogeological textbooks. The main reference sources are listed at the end of this report.

2 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 (short flow path, quick response time), intermediate and regional (long flow path, slow response time) systems. This terminology should not be confused with that used in classic groundwater textbooks (eg. Freeze & Cherry, 1979; Fetter, 2001) for the nested flow systems that develop in groundwater basins, depending on the basin length to depth ratio and the topographic undulation. The terminology used by the Audit, describes local, intermediate and regional GFS by their flow path length and corresponding ability to respond 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).

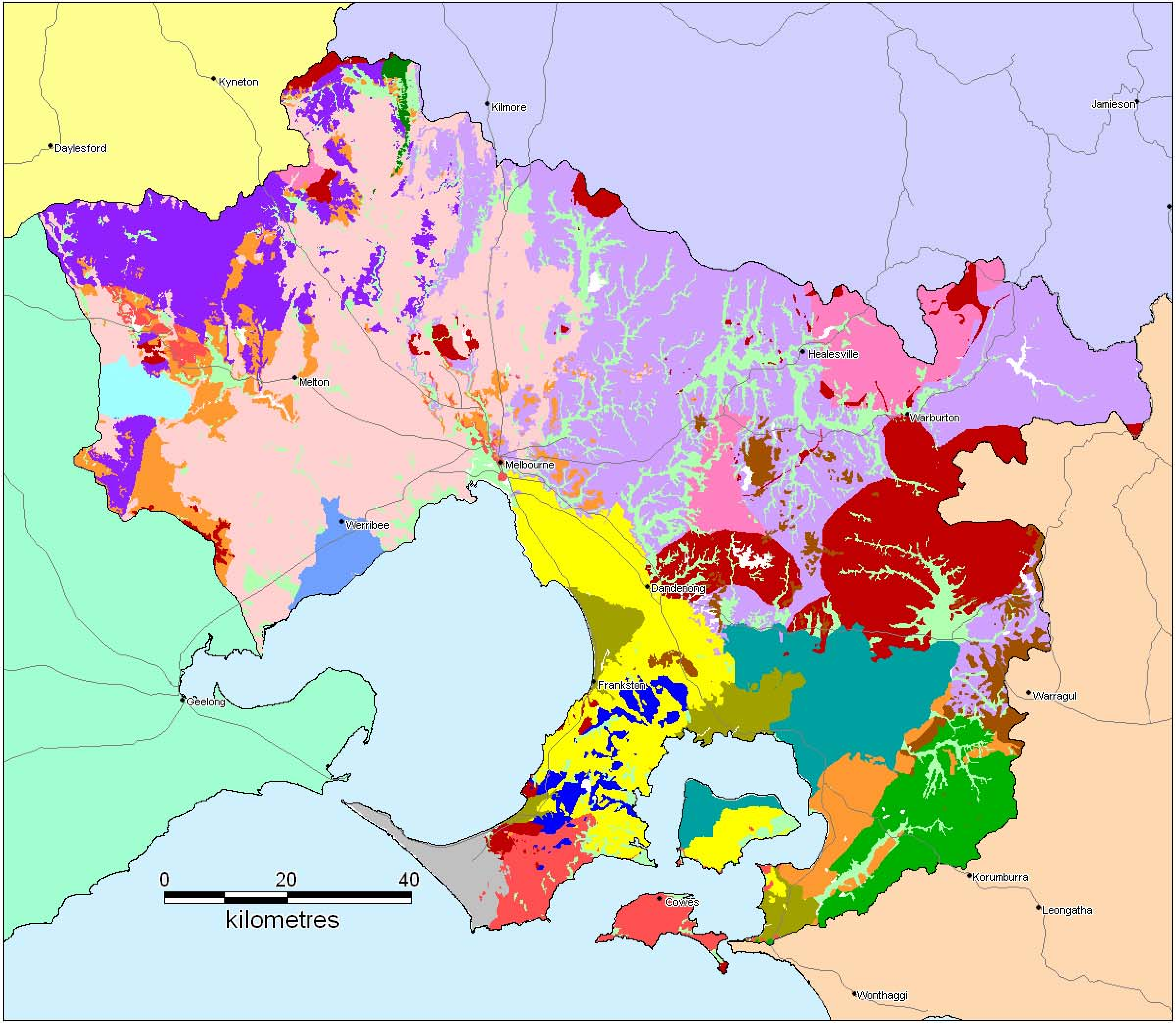
Attribute	Rating	Meaning/Value
Scale	Local	Groundwater flows over distances <5km
	Intermediate	Groundwater flows over distances 5 – 30km
	Regional	Groundwater flows over distances > 50km
Aquifer transmissivity	Low	Less than 2 m^2/day
	Moderate	2 m^2/day to 100 m^2/day
	High	Greater than 100 m^2/day
Groundwater 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).

2.1 PPWP CMA GFS

The 18 GFS recognised in the PPWPCMA region are based on the outcomes of the October 2003 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 PPWPCMA GFS is shown overpage.



Port Phillip and Westernport

CATCHMENT MANAGEMENT AUTHORITY

Groundwater Flow Systems

Local systems

- GFS 1 - Quaternary sediments
- GFS 2 - Gravel and sand sediments
- GFS 3 - Nepean barrier dunes
- GFS 4 - Greenstone ranges

Local and intermediate systems

- GFS 5 - Swamps and backdune wetlands
- GFS 6 - Weathered Older Volcanics
- GFS 7 - Older Volcanic fractured basalt
- GFS 8 - Acid volcanics
- GFS 9 - Granitic rocks
- GFS 10 - Brighton Group sediments
- GFS 11 - Werribee Delta
- GFS 12 - Rowsley Valley complex
- GFS 13 - Mornington fractured bedrock
- GFS 14 - Strzelecki Group rocks
- GFS 15 - Fractured Palaeozoic rocks

Intermediate and local systems

- GFS 16 - Weathered Palaeozoic rocks

Intermediate and regional systems

- GFS 17 - Westernport plain

Regional and intermediate systems

- GFS 18 - Volcanic plains

Version 1, January 2004

3 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: The map polygons show the boundaries of each GFS at the Earth's surface and do not indicate their extent at depth. The boundaries of each GFS are based on the combination of geological outcrop, land systems, landforms and local expert knowledge.

Region: The general geographic location of the GFS within the PPWP CMA is stated.

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

Description: A brief overview of the geology and groundwater flow for the GFS.

Problem statement. The 'salinity problem statement' provides context for the GFS's role in the salinity issue.

3.1 Landscape attributes

Geology: Geological units derived from the GSV 1:250,000 digital geology map.

Topography: Description of the landforms of the GFS area.

Land Systems: As mapped in the Land Systems of Victoria (Rees, 2000).

Regolith: General description of regolith (weathered mantle) materials.

Annual rainfall: Range in millimetres derived from the Bureau of Meteorology's rainfall model (CLPR, 2003).

Dominant mid-1800s vegetation type: General description of native vegetation cover for the GFS area, derived from the Land Systems of Victoria (Rees, 2000).

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

Mapping method: Method used to delineate the GFS boundaries.

3.2 Hydrogeology

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

Aquifer type (conditions): Unconfined, semi-confined (leaky confined), 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 groundwater flow distances from recharge to discharge.

Catchment size: Estimate of the recharge and discharge area of a flow system.

Recharge estimate: Recharge estimate in millimetres (depth) per year.

Temporal distribution of recharge: Estimate of when recharge occurs.

Spatial distribution of recharge: Estimate of where recharge occurs.

Aquifer uses: Description of groundwater uses.

3.3 Salinity

Groundwater salinity (TDS): Salinity range of the groundwater in mg/L.

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

Salinity occurrence: Description of where salinity occurs in the landscape.

Soil Salinity Rating: S1, S2, or S3, based on the DPI's standard rating (Allen, 1996)

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

Salt impacts: Stated as either on-site or off-site impacts.

3.4 Risk

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

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

Assets at risk: A general description of the PPWPCMA region's assets at risk.

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

3.5 Conceptual model(s)

A variety of cross-sectional models illustrate the conceptualised groundwater flow for the system. The models are schematic only and based on the consensus of opinion of those who attended the second day of the October 2003 workshop.

4 Salinity Management Options

At present, some regions within the PPWP catchment are undergoing intense land use change, in particular through urban growth of the metropolitan area and satellite centres, and the establishment of irrigated horticulture in conjunction with waste water reuse. Land use change is being led in strategies and programs such as Melbourne 2030 and Grow West. Projected land use change has significant implications for the management of salinity discharge in the PPWP CMA region, which must look beyond the traditional opportunities offered in typical dryland grazing/cropping regimes that are so relevant in other CMAs.

Taking account of this changing land use, the description of salinity management options for each relevant GFS includes a brief discussion of the implications of projected land use, in addition to the applicability of the various management options related to dryland agricultural systems. The dryland agricultural options are presented in tabular form (the general template used in the GFS descriptions in the neighbouring CMAs), whilst reference to other land uses and management options is of a descriptive nature. This difference in presentation reflects the relative mature knowledge that we have of salinity management for dryland agricultural systems compared to other land uses such as irrigated horticulture and urbanisation. For the latter land uses, the neat partitioning of solutions and opportunities is not possible, since the level of understanding of hydrologic impacts, and the tools to deal with these impacts, is lower.

4.1 Salinity management and groundwater flow systems

The temporal and spatial impacts of salinity management techniques in the landscape are principally a function of:

- whether it deals with the cause or effects of salinity

- the hydrogeological responsiveness of that landscape that is in turn, a function of the length of flow path, system permeability, depth of weathering etc.
- the scale of application of the management option relative to the extent of the flow system
- the climatic regime in which it is implemented
- land suitability for a particular control measure

The scale and responsiveness of the flow system frames the general land management response, especially the relative effectiveness of recharge management, discharge management, or planning/engineering to protect assets from degradation due to salinity. In respect to biological salinity control measures, climate and land suitability are important determinants as to their technical application.

The management opportunities suggested for each PPWCMA GFS are indicative and generalised, and certainly not definitive. Groundwater flow systems represent only a coarse and generalised classification, and at the implementation scale, GFS attributes may not accurately reflect the physical conditions (and therefore the opportunities) at a particular site. In addition, the management options are based on the salinity-affected parts of a GFS. In reality, where salinity is not a known issue within a GFS (not to say that there will not be an issue in the future), precautionary salinity management (e.g. recharge control) is considered impracticable, and is therefore not included.

Confidence in management options for the protection of different classes of assets requires confidence in the conceptual model of how the groundwater and salinity processes operate. This is not always the case, and, where this is such an issue, mention is made in the management option preamble for the GFS. One challenge in adopting the GFS approach to salinity management in the PPWCMA region is the emergence of a variety of conceptual models for salinity processes, even within a single GFS (a question of resolution).

There are a number of examples in the PPWCMA region where speculating on the applicability of various control options demonstrates some of the thought processes critical in making a decisions on salinity management in this region.

Pakenham

The urban growth corridor through Pakenham rests on the upper fringes of the Westernport Plain, where watertables are shallow and surface waterlogging is a common characteristic. The dense stands of waterlogging tolerant Melaleuca which existed in the low-lying areas indicate that the landscape was often saturated. Clearing of the plains and adjacent foothills has probably increased the waterlogging impacts and led to increased soil-salt accumulation. Without significant engineering intervention it is unrealistic to completely alleviate waterlogging from this landscape, and a degree of salinity is an inevitable feature, even when the landscape has been developed. On this basis there may be a need to strategically plan where urban development should occur and impose mandatory engineering standards to safeguard infrastructure from degradation due to salinity.

Clyde North

Isolated salinity occurs at the interface of a local fractured rock groundwater flow system, and a local flow system (believed to be naturally waterlogged) developed in Quaternary alluvium. The salinity tends to occur as break-of-slope discharge, but there the relative influence of the two adjacent GFSs is unclear. Strategic tree planting on the bedrock rises may not achieve the desired result and recharge control using pastures is unsuited due to the higher rainfall. There is pressure for intensive horticultural development and waste water reuse across this region. Without strategic planning based on land suitability, groundwater accessions from irrigation have the potential to exacerbate local waterlogging and salinity. There are implications for the sustainability of these enterprises themselves, in addition to other assets in the local environment.

Balliang

At Balliang the hydrogeological processes causing the salinity remain uncertain, lowering the confidence in the required solution, if recharge control is to be pursued. Rainfall is only moderate (<600 mm), so perennial pasture offers a possibility as a broad acre option. Cropping is practised in the region where soils are amenable, and it would probably be prudent to incorporate appropriate pasture phases that aid in recharge management. Despite the likely opportunities for recharge control, the salinity processes at Balliang have probably reached hydrological equilibrium, and there have been significant works over the years to stabilise the site. The questions arise: 'will the salinity get any worse?' and if not, 'is recharge control sellable?'

4.2 Salinity management opportunities in dryland agriculture

Dryland agricultural salinity 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).

Biological control of recharge: use or manipulation of vegetation to reduce recharge. In addition to direct recharge control, vegetation may reduce runoff and therefore waterlogging in the lower landscape (that may otherwise leave land unproductive, and be a source of indirect or flood recharge). Specific treatments include perennial pastures, crop management and trees/woody vegetation.

In the interpretation of biological recharge control opportunities for the PPWP region there are a number of important considerations:

- scale of flow and responsiveness of system
- rainfall
- soils and land suitability
- likely land use scenarios (e.g. how much land can be spared for trees?)

Much of the PPWCMA region experiences rainfall above 700 mm/yr, so that recharge control through perennial pastures within many GFSs is doubtful. However, the maintenance of healthy pastures will serve to somewhat reduce runoff and waterlogging (and therefore indirect recharge), and thereby reducing salt wash-off into streams. Given that dryland agriculture will remain dominant in these higher rainfall landscapes, an emphasis on risk minimisation rather than risk avoidance is the likely practicable approach.

Technically, the adoption of woody vegetation might resolve recharge, but practically, trees need to be nested into farming systems. In addition, reducing recharge can also reduce catchment run-off, which has implications for water supply. For this reason the interpreted impacts of woody vegetation are relatively tempered in the GFS management option assessments.

Engineering intervention: the use of mechanical means to reduce watertables or remove surface water that would otherwise lead to high watertables or waterlogging. In practice this generally relates to specific treatments that protect assets in zones of high watertables, salinity and waterlogging. Engineering solutions are typically used in discharge or waterlogged areas, but, theoretically could include operations up-catchment to prevent these hazardous conditions occurring. Specific treatments include surface and sub-surface drainage, and groundwater pumping.

In the interpretation of engineering intervention opportunities the following considerations are important:

- technical feasibility (e.g. aquifer permeability? hydraulic gradients?)
- economic feasibility
- disposal of effluent

Given the inability of farming systems to effectively control or mitigate salinity in many instances, engineering options are often put forward as an alternative solution. For instance, they are widely used in the northern irrigation districts. However, in the relatively more pristine and biodiverse environments in dryland areas, disposal of effluent is usually problematic. Another potential issue is the reduction in stream baseflows through groundwater pumping. In addition, the costs and benefit equation of employing an engineering option to protect or restore an asset in a dryland region has rarely been calculated, so that the appreciation of such options has not yet matured.

Productive uses of saline land and water: encompasses biological treatment of discharge areas and/or other productive uses. Specific treatments include salt tolerant pastures, halophytic vegetation, salt tolerant vegetation, saline aquaculture and salt harvesting.

In the interpretation of saline land management opportunities the following considerations are important:

- climate (e.g. does it suit halophytes?)
- technical feasibility (e.g. is there enough salt to harvest?)
- economic feasibility (e.g. does the saline land need to be developed?)
- social feasibility (e.g. does saline aquaculture suit the local environs?)

In the PPWCMA region, as for most areas, the direct treatment and stabilisation of saline ground is a reasonable objective in its own right. Whilst there is a natural tendency to want to directly treat highly visual and geographically distinct issues (as opposed to the more problematic issue of dealing with the diffuse nature of recharge), treatment of discharge areas has the relatively short term benefit of reducing the amount of salt wash-off to streams, whilst other catchment management solutions take effect.

In the PPWCMA region there is probably more potential in the use of salt tolerant pastures rather than halophytes given the climatic constraints with respect to applying the latter. In and adjacent to urbanised areas and conservation areas there are questions in regards to the aesthetics of salinity discharge management, in addition to the potential invasiveness of salt tolerant species. In public open spaces such as golf courses, salt and waterlogging tolerant grasses present a management option (e.g. the use of Santa Anna Couch at the Pakenham Golf Course).

Productive uses of saline ground such as saline aquaculture and salt harvesting are highly problematic, and require strong economic foundation before they will proceed. Their overall impact on salinity management in the PPWCMA region will be minimal, though, technically, they nevertheless present local salinity management opportunities.

Other: other options to consider. Generally refers to the OPUS database, available on the National Dryland Salinity Program website.

4.3 Salinity management opportunities for irrigated agriculture and horticulture

Issues

The hydro(geo)logical issue with irrigated agriculture is the introduction of additional water into the landscape that would not otherwise be there (in volume and temporal distribution), that to varying degrees can be managed to minimise accessions to the watertable. In the PPWCMA region there a number of hydrogeological boundary conditions that are important in the consideration of irrigated cropping, including:

- Waterlogging and shallow watertables (in many instances a natural condition)
- Down-basin groundwater elevations maintained by permanent sea levels
- Variable, but often high annual rainfalls exceeding 700 mm

Dealing with current issues

Management strategies to deal with currently expressed salinity issues in irrigation environs include:

- isolating, stabilising and potentially increasing productivity from salinity affected areas
- increasing the efficiency of irrigation applications to reduce accessions
- where possible, improved drainage of excess surface and sub-surface water

Planning for future issues:

It is important that land suitability surveys are undertaken to focus development on the most appropriate soil, and where on and off-site damage will be minimised. Planning should establish safeguards in order to minimise impacts. In some circumstances avoidance of irrigated agriculture/horticulture may be the desirable choice rather than simply impact minimisation.

4.4 Salinity management opportunities for urbanised environments

Issues

The hydro(geo)logical issues associated with urbanised areas are complex. On the one hand, heavily paved areas limit the capacity for direct recharge and routes accumulated surface drainage through a highly engineered drainage network. On the other hand, garden irrigation (and potentially leaky drainage systems) increases the opportunity for localised recharge. Human Infrastructure may disrupt both natural surface and sub-surface drainage patterns with implications for salinity development.

Dealing with current issues

Management strategies to deal with currently expressed salinity issues in urbanised environs include:

- stabilisation and beautification of salinity affected areas by vegetative means
- surface and/or sub-surface drainage to protect assets
- reduction of recharge accessions by minimising garden watering and maintaining drainage infrastructure

Planning for future issues:

A satisfactory urban planning framework encompassing salinity would determine the protocols or guidelines under which development could occur (for instance based on the distribution of salinity and shallow watertables), and then construction regulations governing the nature of building for a particular set of physical environmental parameters. In some instances it may be decided that urban development is prevented in order to avoid the costs associated with the future salinisation impacts. Where development is in place or is planned to occur in the future, planning schemes might also consider urban watering restrictions.

4.5 Planning frameworks

Salinity management in the GFSs can be seen in terms of whether the measure *mitigates* salinity, *avoids* salinity (even if the hazard cannot be avoided, good planning may avoid assets being exposed to the hazard), or *adapts* to salinity. With significant land use pressures at play in the region, much of the emphasis will likely be on avoiding or adapting to salinity, in which case strategic planning of development is crucial.

The experience with salinity overlays in municipal planning frameworks across Victoria has generally been an unsatisfactory one. How does one use a salinity overlay? How do you define boundaries on the ground? How does it link to process? How can you form a sound planning argument? The answers to such questions are not possible with such limited information provided in a traditional salinity overlay, and there is usually no process in place to allow a planning officer to answer these in order to develop a sound planning argument.

The keys to an effective planning scheme that considers salinity are:

- a set of informative overlays, not restricted to the distribution of salinity, but incorporating watertable information, GFS characteristics, etc.
- a framework that allows a pathway to interpreting of this information to make a sound planning decision. This would likely require the onus to disprove, manage or avoid salinity hazard to be with the developer.

5 Considerations in using GFS for salinity management

The 18 GFS presented in this report are similar landscape-groundwater systems which give effect to similar salinity issues and therefore, similar management options may apply. However, for each system the confidence in the options for salinity management is constrained by the lack of scientifically validated models relating the assumed cause (land-use change) to the observed effect (salinity). In fact, the manifestation of salinity in each landscape is a function of the relationship between the geology, hydrogeology, landscape evolution, climate, environmental history and current land-use.

In Australia, salinity research has focused on the hydrologic changes associated with land-use changes in the rural environments, particularly agriculture. In comparison, regional-scale hydrologic changes associated with urban development are poorly understood. The effect on regional groundwater tables of converting agricultural land to suburbs has not been widely investigated, but has a potentially greater impact on the hydrologic balance than most land use changes. Salinity management should ensure that existing saline areas are not urbanised without appropriate asset protection measures, and that the urban development will not initiate salinity by changing the hydrologic budget.

Appropriate salinity management also needs to recognise that land and water salinity are the basis for some of the region's environmental assets of international importance. The saline wetlands, salt mashes and mangrove thickets of Port Phillip (western shoreline) and Westernport are global assets listed under the Ramsar Convention on Wetlands. These assets require appropriate surface water and groundwater management to protect the (primary) saline wetlands from threats such as urban stormwater input or over-pumping aquifers. Conversely, to protect the water quality of the Ramsar-listed Edithvale-Seaford Wetlands, engineering intervention is currently used to prevent interactions with the underlying saline groundwater (EA, 2004).

Urban development at Berwick. This type of land-use change has the potential to rapidly alter the regional hydrology.

Port Phillip and Westernport Groundwater Flow Systems

Number	Dominant Flow System	Sub-dominant Flow System	Description
GFS 1	Local		Quaternary sediments
GFS 2	Local		Gravel and sand sediments
GFS 3	Local		Nepean barrier dunes
GFS 4	Local		Greenstone ranges
GFS 5	Local	Intermediate	Swamps and back-dune wetlands
GFS 6	Local	Intermediate	Weathered Older Volcanics
GFS 7	Local	Intermediate	Fractured Older Volcanics
GFS 8	Local	Intermediate	Acid volcanics
GFS 9	Local	Intermediate	Granitic rocks
GFS 10	Local	Intermediate	Brighton Group sediments
GFS 11	Local	Intermediate	Werribee Delta
GFS 12	Local	Intermediate	Rowsley Valley complex
GFS 13	Local	Intermediate	Mornington fractured bedrock
GFS 14	Local	Intermediate	Strzelecki Group rocks
GFS 15	Local	Intermediate	Fractured Palaeozoic rocks
GFS 16	Intermediate	Local	Weathered Palaeozoic rocks
GFS 17	Intermediate	Regional	Westernport plain
GFS 18	Regional	Intermediate	Volcanic Plains

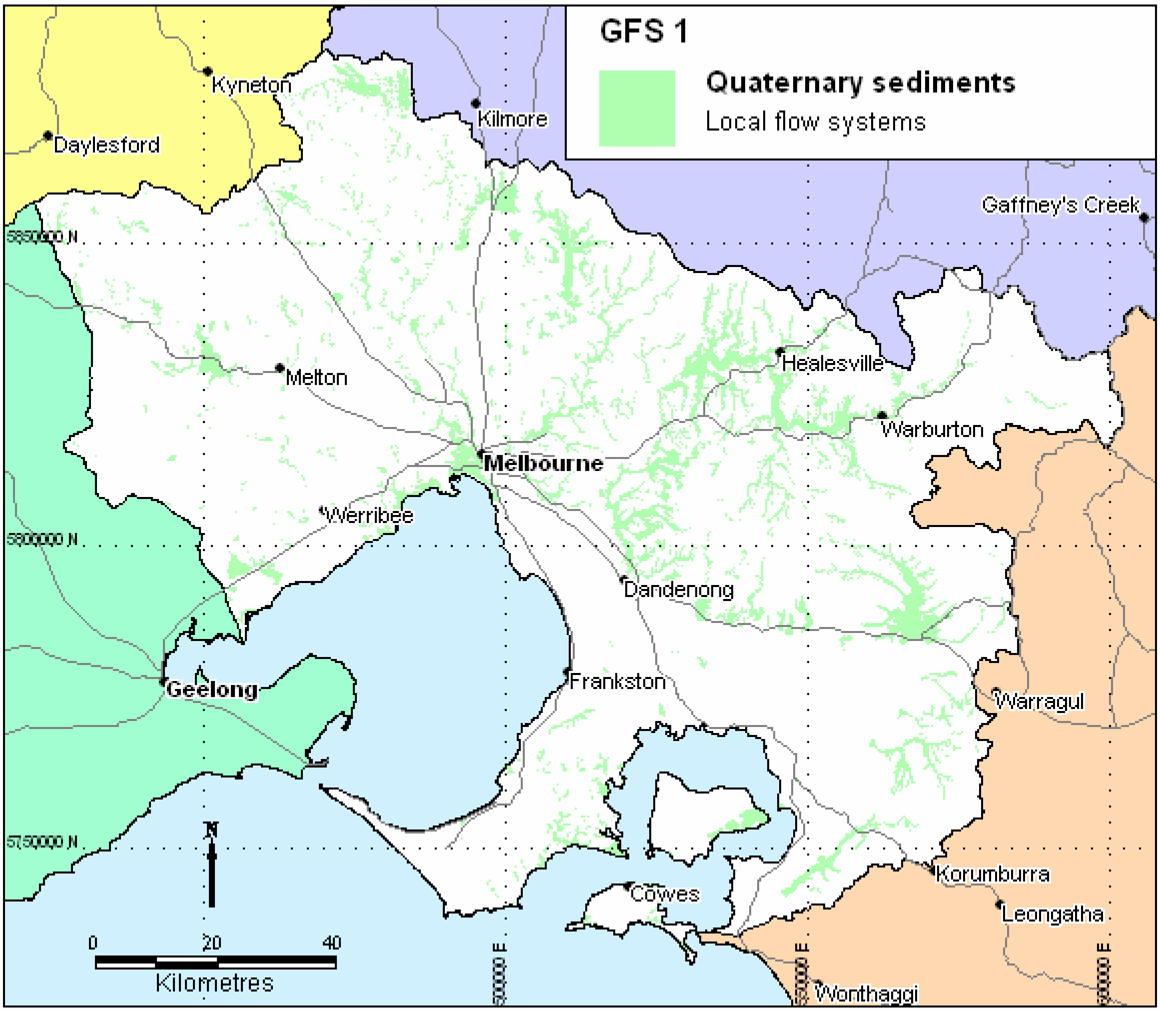
GFS 1 Local flow systems in Quaternary sediments

Region: All of PPWP CMA

Type areas: Bacchus Marsh, Yarra Glen, Longwarry North.

Brief description: Deposits of Quaternary age sediments are widespread over the PPWP CMA region. These include stream alluvium, hillside colluvium, swamp and lake deposits, lunettes, recent marine sediments and coastal dunes. Although these deposits vary in thickness, formation and materials, they are grouped together by similar hydrogeological processes. Some deposits of coarse-grained materials and the larger regional deposits of the Westernport coastal plain, Bass coastal plain, Werribee Delta, Nepean Peninsula, Carrum Swamp and Koo-wee-rup Swamp are either designated as separate groundwater flow systems or included with other groundwater flow systems. A notable exception is the Yarra Delta, which is included in this GFS even though it is composed of sequences of units and has a more complex flow regime than the other Quaternary flow systems.

Groundwater moves at varying rates through the unconsolidated deposits in local flow systems that generally develop at shallow depths below the ground surface. Salinity is strongly correlated with this GFS, particularly in the Upper Maribyrnong River catchment. Along the western shore of Port Phillip Bay, primary salinity is a feature of the coastal and estuarine environments of Point Cook and Point Wilson.



Problem statement: In general, changes in the water balance resulting from land-use change has increased soil waterlogging, changed regolith hydrology, and increased groundwater recharge and discharge.

Landscape attributes

Geology: Quaternary alluvium (Qra, Qpa, Qp2), Duetgam Silt flood plain deposits (Qpw), Coode Island Silt lagoon deposits (Qpy), alluviual terraces (Qrt); Quaternary colluvium and gully alluvium (Qrc, Qpc); Neogene post Newer Volcanics alluvium (Tpe) and hillwash (Tpo);

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

Land Systems:

<u>Central Victorian Uplands</u>

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands – Midlands

<u>South Victorian Uplands</u>

3.3 Moderate Ridge – Mornington Peninsula

3.4 *Dissected Fault Block – South Gippsland Ranges*

<u>Western Victorian Volcanic Plains</u>

7.1 Undulating Plains – Western District

7.2 Stony Undulating Plains – Western District

<u>South Victorian Coastal Plains</u>

8.3 Sand and Clay Plains - Moorabbin

8.4 Fans and Terraces – Westernport

8.5 Barrier Complexes – Discovery Bay, Gippsland Lakes

<u>South Victorian Riverine Plains</u>

9.1 Present Flood Plain - Gippsland

Regolith: Unconsolidated gravel, sand, silt and clay.

Annual rainfall: 500 mm to 1700 mm

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

Current dominant land uses: Urban and industrial development (including City CBD and Docklands), waterways, parkland, horticulture, viticulture, grazing, conservation.

Mapping method: Outcrop geology, landform and local knowledge.

Saline wetlands at Kirk Point, near Avalon, an example of primary salinity as an environmental asset.

Hydrogeology

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

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

Hydraulic Conductivity (lateral permeability): Extremely variable. Probable range from 10^{-6} m/d to 10^{2} m/d, with clayey facies less than 1 m/d and sandy facies up to 100 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 0.05 to 0.3.

Hydraulic gradient: Varies with landscape and topography. Very low to low in river and swamps, and moderate to locally steep in colluvial slopes.

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: Probably 10% to 20% of local rainfall, but would vary with the landscape setting at any location.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years. Extensive periods of soil waterlogging may add to local recharge.

Spatial distribution of recharge: Catchment wide.

Aquifer uses: Irrigation, and minor stock and domestic use from shallow bores.

Salinity

Groundwater salinity (TDS): Generally in the range of <1,000 mg/L to 10,000 mg/L TDS.

Salt store: Moderate to high.

Salinity occurrence: Secondary salinity occurs in low lying and flat areas, drainage lines, swampy wetlands, and at the foot of colluvial slopes. Some primary salinity associated with the estuarine environments.

Soil Salinity Rating: S2, S3

Salt export: Wash off from surface.

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

Risk

Soil salinity hazard: High.

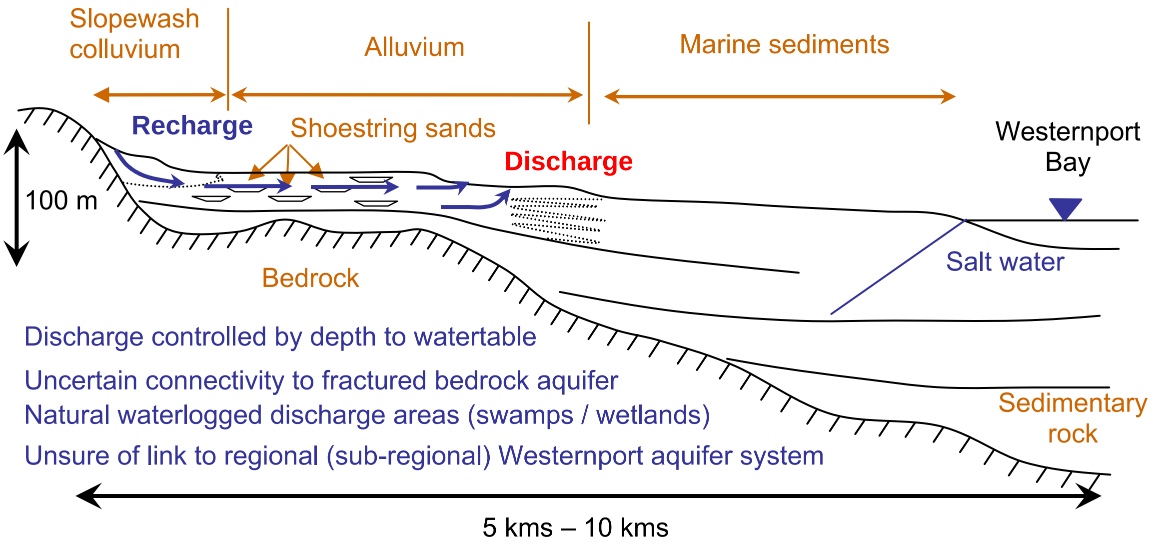
Water salinity hazard: High.

Assets at risk: Water quality and aquatic biodiversity (Maribyrnong River system), urban infrastructure (Pakenham), agricultural land (Rockbank, Lancefield, Tyabb), wetlands and conservation areas (Phillip Island, Point Cook, Pelican Point), engineering infrastructure.

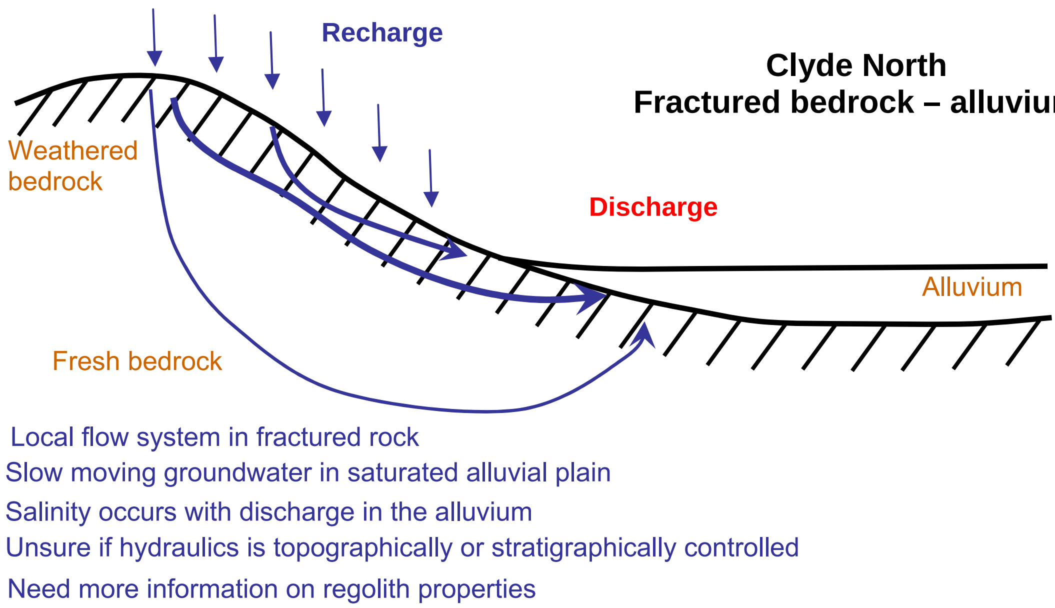
Responsiveness to land management: Varied, but generally should be very responsive. In some areas, the influence of the underlying groundwater flow systems is more significant, and land management in this groundwater flow system is not as effective.

Conceptual models

Pakenham footslopes



Clyde North
Fractured bedrock – alluvium



Two conceptual models of groundwater movement and salinity processes associated with Quaternary sediments.

At Sanctuary Lakes, an Environmental Audit for large residential development associated the salinity with the former salt condensers, concluded that a slug of high salinity groundwater (>40,000 mg/L TDS) is present under the lake, complete with a salt water / fresh water wedge.

Management Options

Within the PPWP CMA region the salinity hazard posed by this GFS is relatively minor, although there are particular areas where the hazard is concentrated. Where salinity does occur it is often in areas (Pakenham and Clyde North) that were naturally water-logged and probably brackish. Salinity control in these circumstances would aim at reducing (but not eliminating) the extent and magnitude of waterlogging and salinity.

The Quaternary sediments often occur in parts of the landscape that are transitional between fractured rock uplands and broader plains and lowlands, and are therefore influenced by the hydrological processes occurring in these neighbouring landscapes. Owing to their limited lateral extent, the management of salinity in the Quaternary sediments will have minimal impact on downstream GFSs.

In some areas of primary salinity, particular management strategies 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 Port Phillip Bay and Western Port Bay.

Dryland agriculture options for managing salinity in local flow in the **Quaternary sediments**.

Salinity focus: Pakenham, Clyde Nth

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low impact – salinity affected alluvial plains interpreted to be naturally waterlogged. Rainfall above 700mm.
	Crop management	Low impact– rainfall above 700mm
	Trees/woody vegetation	Low to moderate impact– some potential for recharge and waterlogging control on plains/swamps, but requiring high density revegetation (unlikely)
Engineering intervention	Surface drainage	Low impact– little ability to intercept surface water except on gradient footslopes. Disposal issues
	Groundwater pumping	Low impact– limited opportunities, but where asset protection makes it warranted. Shoestring sand aquifers where identifiable present potential pumping sites
Productive uses of saline land and water	Salt tolerant pastures	Moderate impact– waterlogging tolerance required on flats.
	Halophytic vegetation	Low to Moderate impact– generally poorly suited to climate
	Saline aquaculture	Low impact– not suited to environs
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	Consider revegetating low lying areas with indigenous waterlogging and salt tolerant trees (e.g. Melaleuca). See OPUS database (NDSP)

Management implications given projected land use

Development pressures are apparent at both the Pakenham (urbanisation) and Clyde North (waste water re-use) salinity affected locations. Both regions are predisposed to broad areas of shallow watertable and surface waterlogging. This has significant implications for the viability of both forms of development, and could lead to preclusion of development in some instances. Where development does occur it may need to be engineered to withstand local conditions, and may need to avoid applying additional hydrological loadings across the landscape.

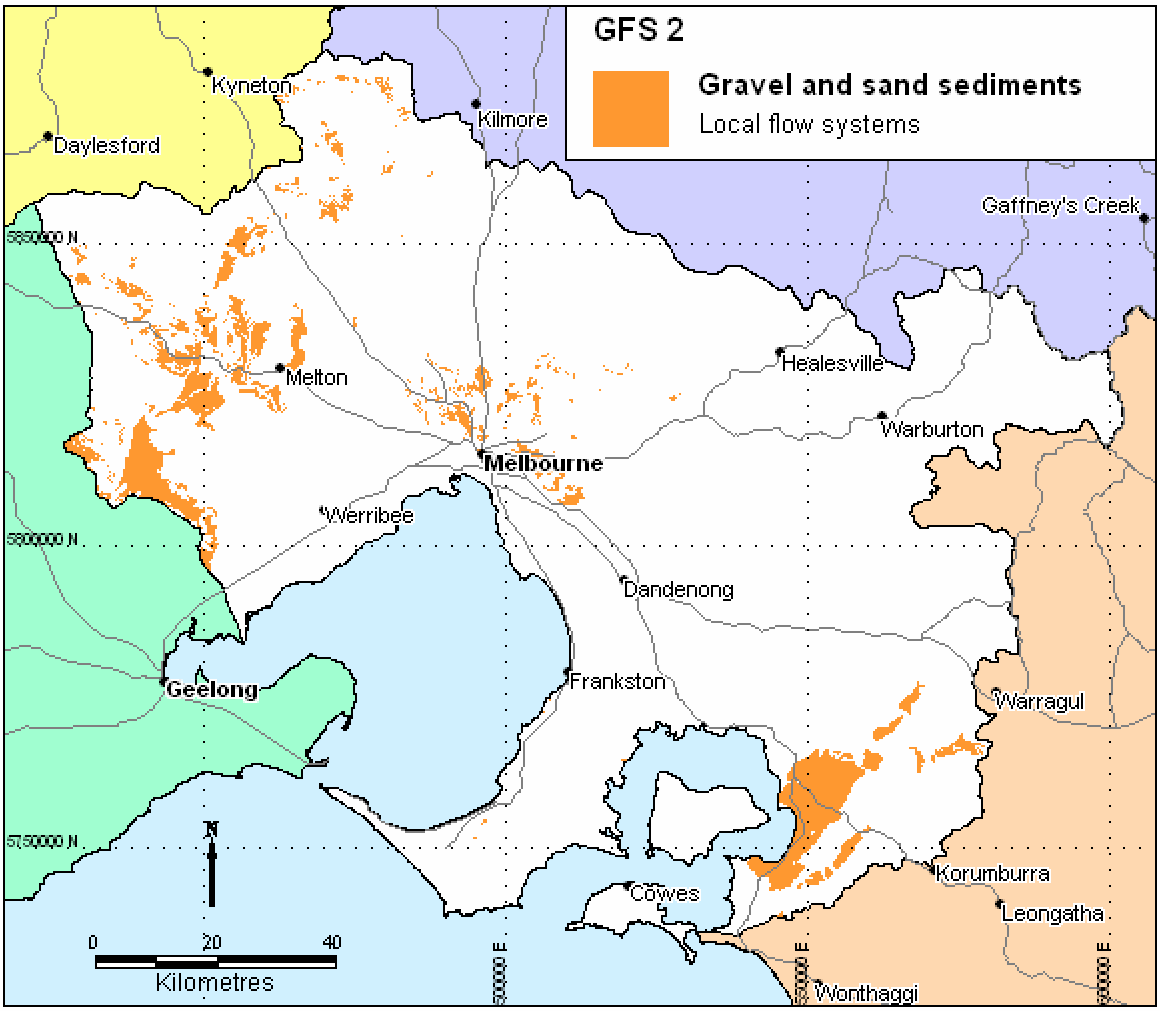
GFS 2 Local flow systems in gravel and sand sediments

Region: Mainly western and south eastern parts of PPWP CMA

Type areas: Lang Lang, Balliang, Melton

Brief description: A variety of relatively discrete sand and gravel deposits of varying geological ages have been grouped together on the basis of their similar hydrogeological character. These include Permian age glacial deposits; remnants of Neogene age gravel deposits which cap the older rocks; sands and gravels which occur as both outwash deposits and sediments interbedded with the volcanics; and Quaternary age outwash deposits from fault scarps.

Groundwater generally moves slowly through the deposits in local flow systems. In the some of the older gravels, the precipitation of iron has cemented the otherwise unconsolidated deposits. The cementation could at least locally, significantly modify flow paths so that groundwater emerges 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. Where the gravels extend under the volcanic flows, some vertical recharge occurs as leakage through the overlying fractured basalt.



Problem statement: Secondary dryland salinity is associated with this GFS at Riddell and near Balliang. The Balliang site is probably the most severe in the PPWP CMA region. The salinity probably results from hydrologic imbalance associated with past landscape change and present land use.

Landscape attributes

Geology: Permian fluvioglacial deposits of the Bacchus Marsh Formation (tillites, diamictites, sandstones, mudstones, conglomerates). Neogene fluvial gravels, sands and silts (Tpb, Tpe, Tph, Tpo) including the Haunted Hill Formation, Moorabool Viaduct Formation equivalents and Brighton Group equivalents. Quaternary alluvium (Qra, Qpa), collvium and gully alluvium (Qrc), lagoon and swamp deposits (Qrm).Quaternary colluvium and gully alluvium (Qrc, Qpc)

Topography: Gently sloping piedmont plains, colluvium and scree slopes, river terraces, ridge caps and undulating low hills.

Land Systems:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands – Midlands

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

3.4 Dissected Fault Block – South Gippsland Ranges

Western Victorian Volcanic Plains

7.1 Undulating Plains – Western District

South Victorian Coastal Plains

8.4 Fans and Terraces – Westernport

South Victorian Riverine Plains

9.1 Present Flood Plain - Gippsland

Regolith: Unconsolidated gravel, sand, silt and clay; ferruginised and silicified gravels and sands; tillite and diamictite.

Annual rainfall: 500 mm to 1650 mm

Dominant mid-1800s vegetation type: Woodland, Forest, Grassland, Rushland, (dependent on location).

Current dominant land uses: Urban and industrial development, waterways, parkland, grazing, cropping, horticulture, conservation.

Mapping method: Outcrop geology, landform, local knowledge

Right:

Salinity at Balliang

Hydrogeology

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

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

Hydraulic Conductivity (lateral permeability): Highly variable and largely unknown. Probably ranges from 10^{-4} m/d to 10^{2} m/d, with clayey facies < 1 m/d; sandy facies up to 100 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 (<1 Ha to 1000 Ha).

Recharge estimate: Unknown. Possibly 10% to 20% of rainfall where exposed at the surface.

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 (GFS 18) in places (eg Melton South).

Aquifer uses: Minor stock and domestic use.

Salinity

Groundwater salinity (TDS): In the range of 1000 mg/L to 10000 mg/L, generally between 3,000 mg/L and 8,000 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 and in drainage lines.

Soil Salinity Rating: S2 to S3.

Salt export: Wash off from surface.

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

Risk

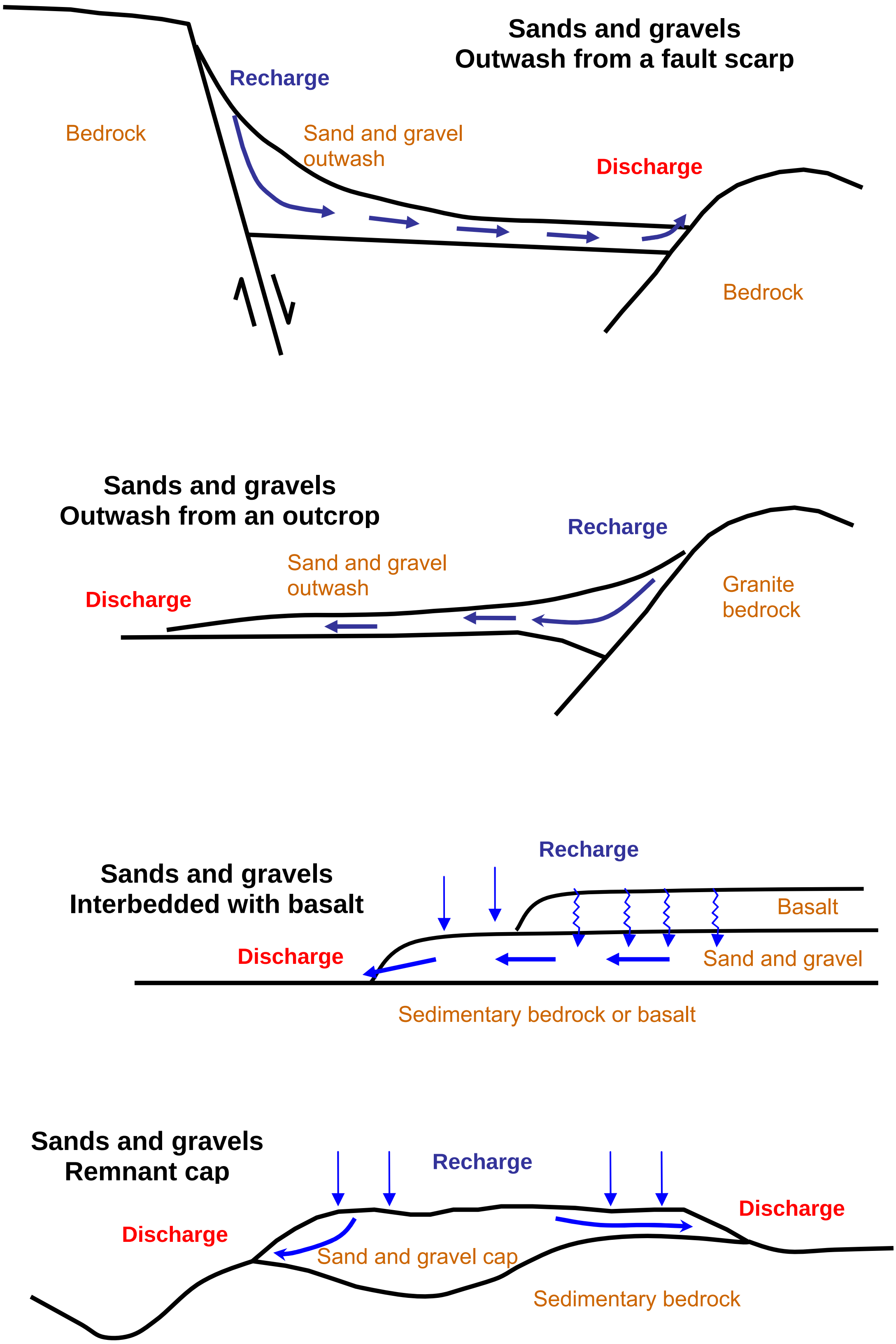
Soil salinity hazard: Moderate to High (scalding).

Water salinity hazard: Moderate.

Assets at risk: Water quality and aquatic biodiversity of Little River and Emu Creek, agricultural land (Balliang, Riddell, Lancefield).

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

Conceptual models



A variety of conceptual models for salinity processes in different geological settings. The common theme is the lateral flow of groundwater through the sand and gravel GFS.

Management Options

This is a geologically and climatically diverse GFS, though the known salinity hazard is mostly confined to the Balliang and Riddell districts. Although the hydrogeological processes causing the salinity at Balliang are uncertain (is the granitic bedrock/regolith the source, or does it provide a barrier to converging groundwater flow?) the system is believed to have reached quasi- equilibrium, and the salinity may no longer expand significantly. Substantial treatment programs are in place at the site. A particular consideration at Balliang is whether the extent of salinity will substantially worsen, and, if not, whether the costs and benefits of recharge control methods to ameliorate the discharge site can be argued.

In other areas such as Riddell there has been little or no specific investigation of salinity processes.

The management comments offered below assume that groundwater flow in the gravel and sand sediments contribute to salinity.

Dryland agriculture options for managing salinity in local flow in the **gravel and sand sediments**

Salinity focus: Balliang, Riddell

Options	**Treatments**	**Comments**
Biological Management of recharge	Perennial pastures	Moderate to high impact – rainfall below 600 mm (Balliang) so recharge control should be possible. Also offers reduction of runoff and waterlogging
	Crop management	Low to moderate impact– incorporate pasture phase
	Trees/woody vegetation	Moderate– lucerne or trees would be beneficial in all aspects of recharge, runoff and waterlogging control
Engineering intervention	Surface drainage	Low– disposal issues
	Groundwater pumping	Moderate – technically possible given acceptable permeability in sands/gravels. However, disposal issues
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high impact– where site conditions are not too eroded
	Halophytic vegetation	Moderate impact– relatively dry climate (Balliang) so could be conducive to stabilising scalded areas
	Saline aquaculture	Low to moderate impact– possibility at Balliang if sufficient volumes of saline groundwater
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

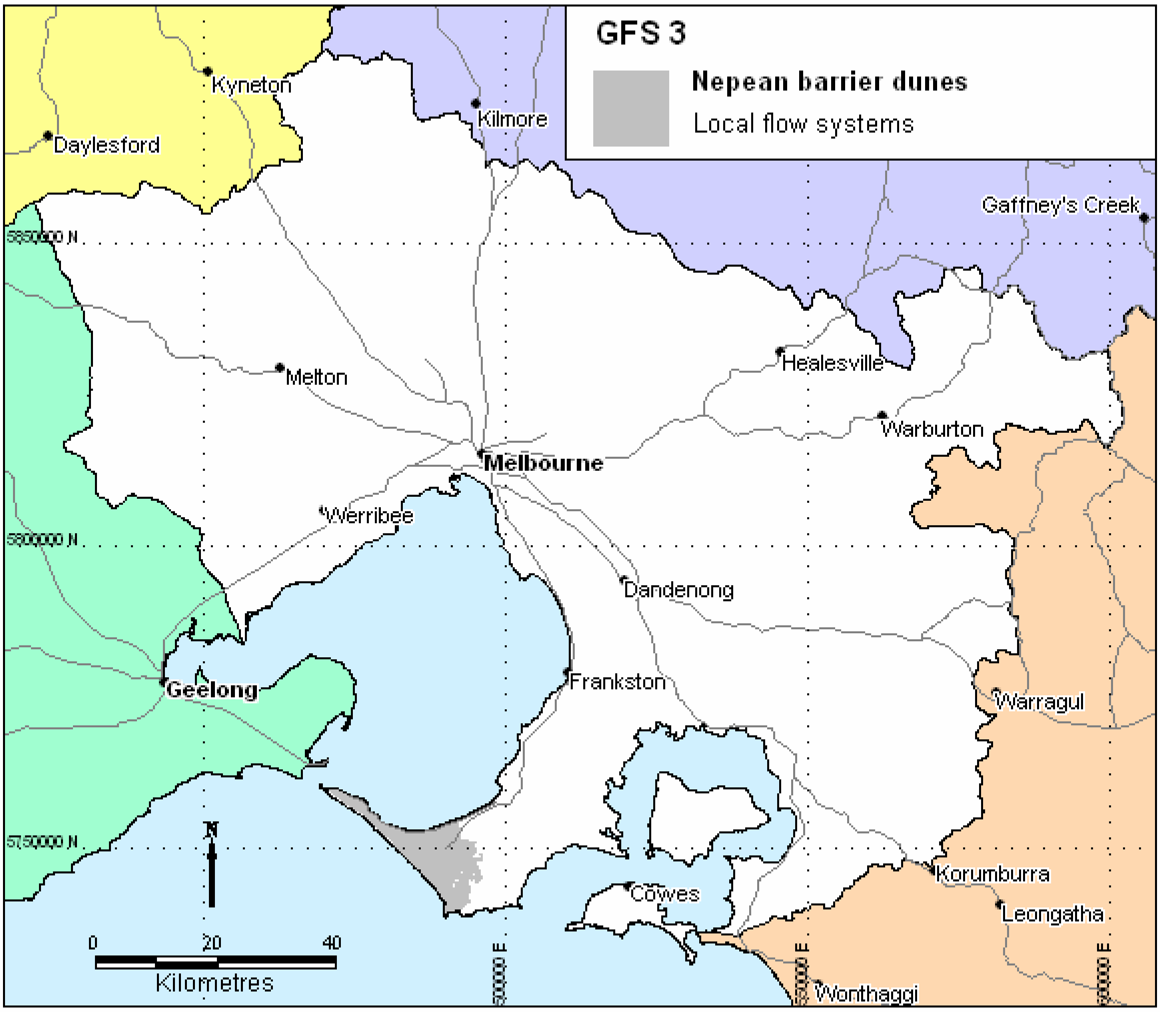
Though the Balliang region is targeted as a zone for possible waste water re-use (irrigation), such developments will tend to occur on the higher quality soils of the adjacent basalt plains.

GFS 3 Local flow systems in the Nepean barrier dunes

Region: Southern central PPWP CMA region (Nepean Peninsula)

Type areas: Rosebud, Portsea, Boneo

Brief description: The Nepean Bay Bar is a complex feature comprising chiefly calcareous aeolian dunes and interbedded palaeosols, marine and beach deposits. The thick sediments (up to 145m) were accumulated as a series of dune ridges and foredunes deposited during a progressively retreating sea in the Pleistocene. The material has been cemented to form aeolianite (calcarenite), although non-calcareous ferruginised sands are present in places.



Problem statement: The Nepean Bay Bar forms a classic freshwater lens over a deeper saltwater (seawater) system. No salinity has been mapped on the Nepean Peninsula, and much of the land is reserved as a National Park. Into the future, groundwater should be managed to ensure that saltwater intrusion does not become a problem.

Landscape attributes

Geology: Quaternary aeolian coastal and inland dunes, dune sand and minor swamp deposits (Qrd), aeolian calcareous dune deposits (Qpd), floodplain deposits (Qpw) and alluvium (Qra).

Topography: To the west, a thin peninsula of undulating sand hills, merging into a gently undulating sand plateau to the east.

Land Systems:

Predominantly:	With some:
South Victorian Coastal Plains	South Victorian Uplands
8.5 Barrier Complexes – Discovery Bay, Gippsland Lakes	*3.3 Moderate Ridge – Mornington Peninsula*

Regolith: Complex mixtures of unconsolidated beach sands, weakly cemented calcarenite, calcrete, calcareous breccia, unconsolidated palaeosols (loams), silts and clays, estuarine organic clays and ferruginised sands.

Annual rainfall: 600 mm to 900 mm

Dominant mid-1800s vegetation type: Scrub and Forest

Current dominant land uses: National Park, urban development, rural residential, recreational parks (especially golf), tourism parks.

Mapping method: Outcrop geology

Hydrogeology

Aquifer type (porosity): Unconsolidated sand, silt and clay (primary porosity), Calcareous aeolianite, brecciated calcrete and limestone, ferruginised sandstone (primary and secondary porosity).

Aquifer type (conditions): Unconfined.

Hydraulic Conductivity (lateral permeability): In the range of 5 m/d to 30 m/d.

Aquifer Transmissivity: Generally less than 1,000 m^2/d.

Aquifer Storativity: Estimated to be from 0.1 to 0.3.

Hydraulic gradient: Generally low, with local mounds under the dunes and moderate gradients near the coast.

Flow length: Generally short, but can range up to a kilometre.

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

Recharge estimate: Probably 20% to 30% of rainfall.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years. Extensive periods of soil waterlogging may add to local recharge.

Spatial distribution of recharge: Catchment wide.

Aquifer uses: Considerable groundwater use for domestic, stock, irrigation, recreational, commercial and industrial uses.

Salinity

Groundwater salinity (TDS): 300 mg/L to 1,200 mg/L.

Salt store: Low

Salinity occurrence: None mapped

Soil Salinity Rating: Low

Salt export: None known

Salt impacts: None known

Risk

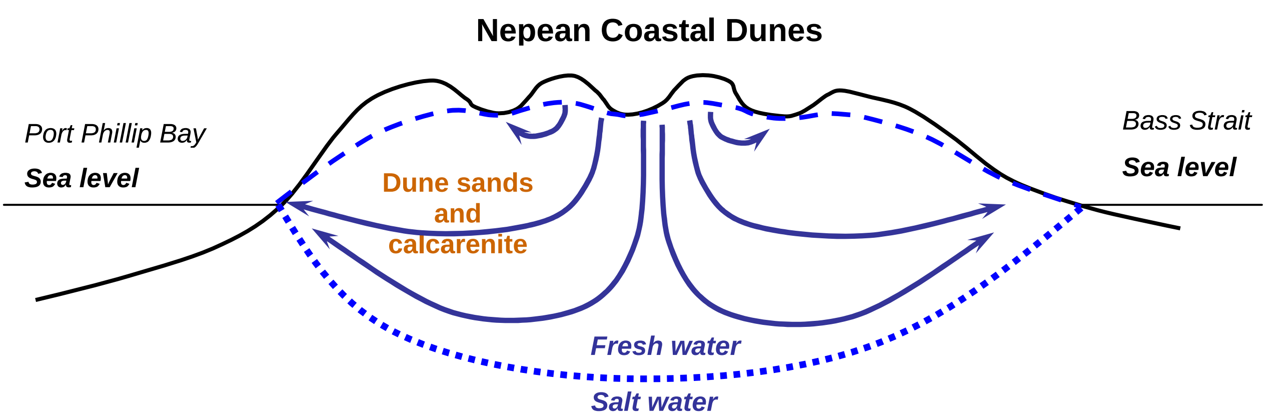
Soil salinity hazard: Low

Water salinity hazard: Low

Assets at risk: None known

Responsiveness to land management: Should be high. Groundwater use needs to be properly managed to prevent saltwater intrusion.

Conceptual model



Management Options

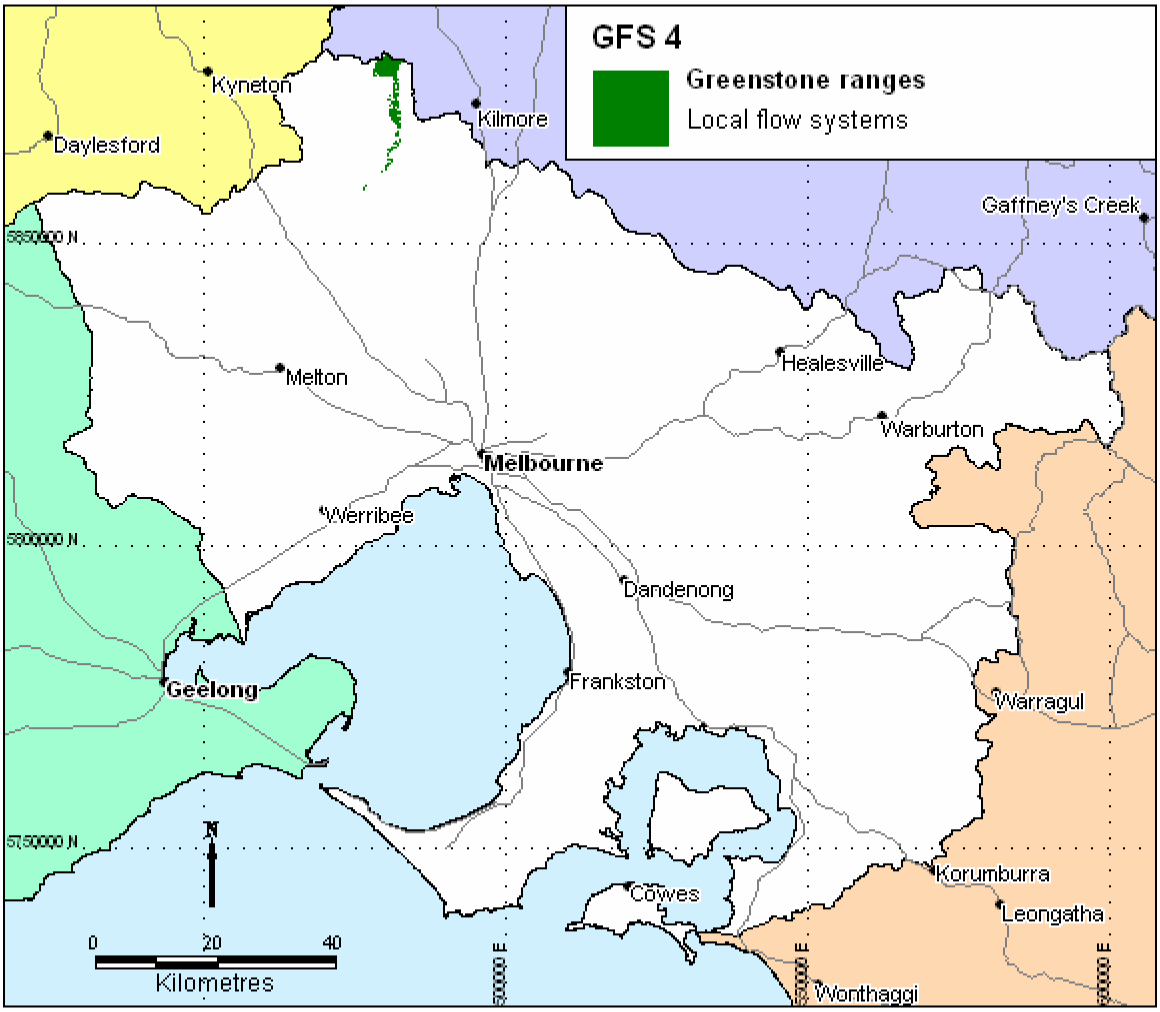
There are no current land salinity issues to be managed. However, into the future, groundwater should be managed to ensure that saltwater intrusion does not contaminate the locally useful stock and domestic groundwater resource.

GFS 4 Local flow systems in the Greenstone ranges

Region: Northern PPWP CMA region

Type areas: Mount William, and connected north-south ridge east of Romsey and Lancefield.

Brief description: The Mount William greenstone belt is recognised as part of the ancient Cambrian seafloor (~ 550 Ma) now exposed along a major geological fault zone. Metamorphosed dolerites and basalts, termed greenstones (Mount William Metabasalt), are overlain by the Knowsley East Shale, which is, in turn, overlain by the Goldie Chert. The sequence of metamorphosed igneous and sedimentary rocks has been tilted and deformed by subsequent tectonic mountain building episodes. Local groundwater flow systems occur in the fractured rocks, although the flow paths can be quite complex.



Problem statement: Salinity occurs as groundwater discharge to the creeks which have formed along the base of the range. These creeks include Deep Creek, and are the upper tributaries to the Maribyrnong River system. The local groundwater flow systems of the greenstone ranges may contribute a component of the salinity, although a complex conjunction of flow systems occur in this region. No salinity has been mapped within this GFS.

Landscape attributes

Geology: Cambrian marine sediments, volcanoclastics, metasediments, and metavolcanics (greenstones) (Emm, Eug, Ev) includes the Mount William Metabasalts, Knowsley East Shale (formerly the Monegeetta Shale) and the Goldie Chert.

Topography: Low ridge formed by a chain of rounded hills.

Land Systems:

Central Victorian Uplands

2.1 West Victorian Dissected Uplands – Midlands

Regolith: A complex mosaic of shallow stony soils, exposed rock outcrop, and deep clay soils, depending on the underlying parent material, slope and landscape position.

Annual rainfall: 700 mm to 850 mm

Dominant mid-1800s vegetation type: Forest with minor Woodland

Current dominant land uses: Grazing, cropping, viticulture.

Mapping method: Outcrop geology

Mount William landscape

Hydrogeology

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

Aquifer type (conditions): Unconfined to semi-confined by the colluvium and alluvium developed along the flanks of the ridge.

Hydraulic Conductivity (lateral permeability): Low. Probably less than 1 m/d.

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

Aquifer Storativity: Probably less than 0.05

Hydraulic gradient: Low to locally moderate

Flow length: Generally from one to three kilometres.

Catchment size: Generally <300 Ha

Recharge estimate: Unknown, but probably quite low.

Temporal distribution of recharge: Seasonal (winter and spring).

Spatial distribution of recharge: Catchment wide where outcrop occurs.

Aquifer uses: Unknown. Some minor use for stock water (if any).

Salinity

Groundwater salinity (TDS): Unknown.

Salt store: Low to moderate.

Salinity occurrence: None mapped within the unit, but some discharge has been reported along the eastern flank. Probably contributes to the salinity in Deep Creek and tributaries to the Upper Maribyrnong River.

Soil Salinity Rating: None mapped.

Salt export: Baseflow contribution to Deep Creek and possible salt wash-off from isolated discharge sites.

Salt impacts: Off-site. On-site unknown, but not considered significant.

Risk

Soil salinity hazard: Low

Water salinity hazard: Moderate

Assets at risk: May impact on the water quality and biodiversity of Deep Creek and the Maribyrnong River.

Responsiveness to land management: Should be high.

Right:

Goldie Chert exposed in a road cutting at Goldie North

Management Options

Salinity currently presents a moderate issue on the Mt William Range, ranging from isolated discharge sites on its eastern flanks to moderately saline baseflow contributed to Deep Creek (albeit this contribution is probably a largely natural one exacerbated by land use change). Given the high rainfall in this area these salinity conditions are unlikely to be significantly altered unless there is substantial revegetation of the range. Maintenance of healthy vegetative cover across the range to reduce runoff, in addition to discharge site treatment, is probably the most practicable solutions.

Dryland agriculture options for managing salinity in local flow in the **greenstone ranges**.

Salinity focus: Lower slopes of Mt. William range

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low to moderate impact– rainfall too high for significant recharge benefit. Healthy pasture coverage will tend to reduce run-off, hence waterlogging
	Crop management	Low impact– generally not significant land use in these landscapes, and rainfall above 700 mm
	Trees/woody vegetation	Low to moderate impact– thinner crest soils will reduce impact. Unless mass plantings (unlikely), scale of impact will be limited. Belts may intercept run-off
Engineering intervention	Surface drainage	Low impact– surface waterlogging not a significant issue.
	Groundwater pumping	Low to moderate impact– cost and disposal issues. Complex fractured rock aquifer.
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high impact– useful to assist stabilising salt affected areas.
	Halophytic vegetation	Low impact– climate not likely to be conducive
	Saline aquaculture	Low impact– not suited to local environs. Only minor discharge
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

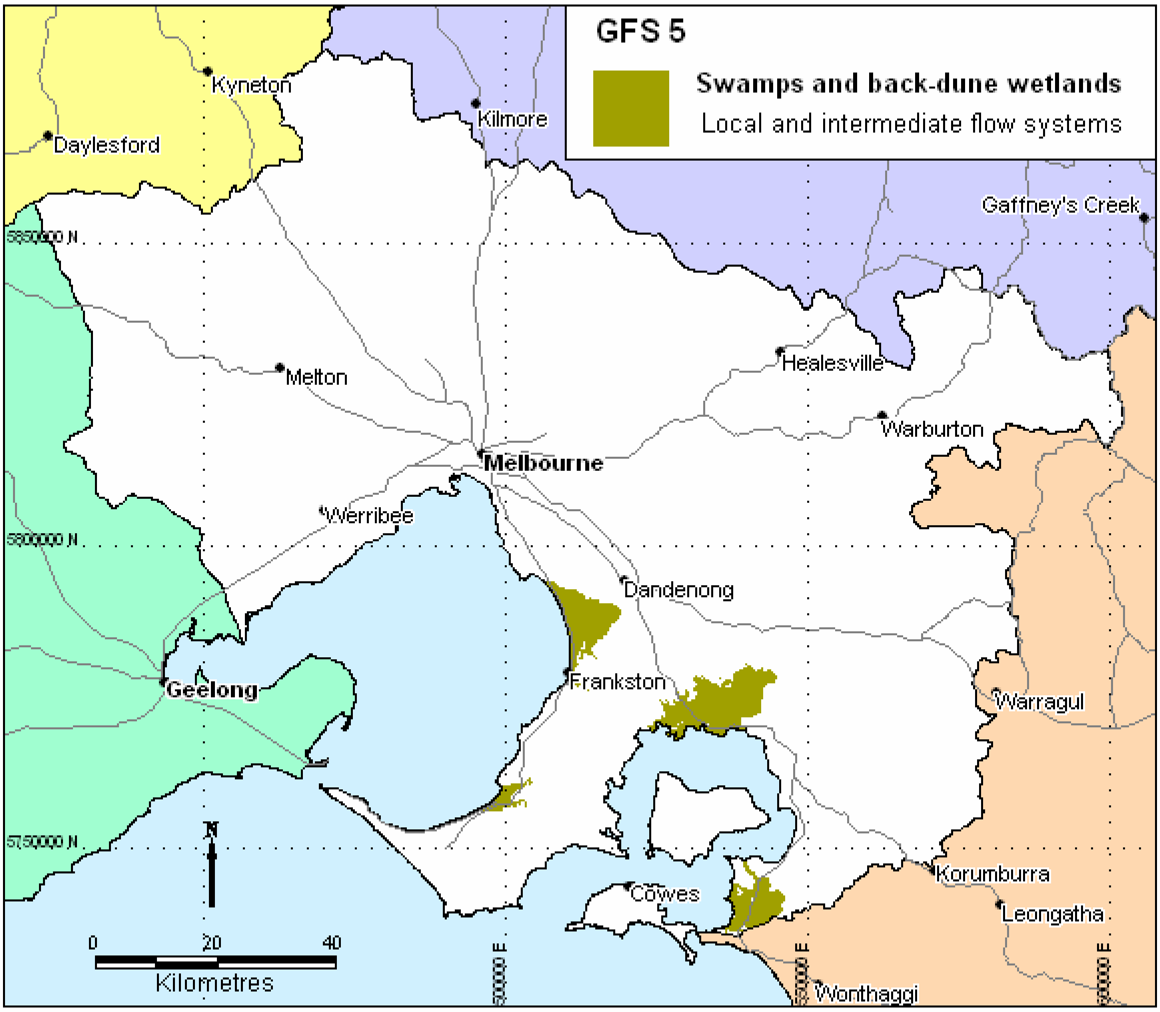
No large scale land use change expected in the short to medium term. Some horticultural development may occur in the future (e.g. vineyards) that may have implication for local hydrology.

GFS 5 Local and intermediate flow systems in swamps and back-dune wetlands

Region: South eastern PPWP CMA region

Type areas: Carrum, Tooradin, Dromana

Brief description: Calcareous and siliceous coastal dunes along the eastern shore of Port Phillip Bay from Mordialloc to Frankston impound the clay, silt, sand and shell deposits of the Carrum Swamp. Estuarine and swampy deposits occur on the eastern shore of Dromana Bay and along the northern shore of Westernport Bay, where they form the Koo-wee-rup Swamp. The lower Bass River forms a small coastal plain on a lowland bounded by the Corinella Fault to the north and the Bass Fault to the south. These alluvial, paludal, littoral and estuarine deposits comprising aeolian sand dunes, beach barriers, raised beaches, estuarine sands, muds, and shell beds are grouped together as one local groundwater flow system. The Carrum and Koo-wee-rup swamps are located at the down-basin ends of underlying intermediate to regional flow systems and probably receive significant input via vertically upward flow from the underlying more productive aquifers.



Problem statement: Permanent and ephemeral groundwater occurs in shallow local flow systems. The salinity is probably derived from evaporation of shallow saline groundwater, exacerbated by the clearing of coastal vegetation such as the removal of Mangroves and Melaleuca swamps. Tidal influences, the movement of the seawater / freshwater boundary and groundwater pumping for irrigation complicates the dynamics of these systems. On the Bass plain, over 400 hectares of secondary salinity have been mapped generally associated with small, shallow depressions in topography.

Salinity associated with this GFS is probably underestimated, especially in the estuarine areas close to the shore. Primary saline areas such as Rutherford Inlet and Quail Island are environmental assets. Seawater intrusion resulting from groundwater pumping is also a potential salinity management issue.

Landscape attributes

Geology: Quaternary calcareous aeolian deposits (Qpd), aeolian coastal dunes, dune sand and minor swamp deposits (Qrd), colluvium and gully alluvium (Qrc), lagoon and swamp deposits (Qrm), Quaternary alluvium (Qra).

Topography: Coastal dunes and barrier dunes, backdune marshland and estuarine flats. Riverine plain of the lower Bass River, merging to a coastal plain, with minor undulations.

Land Systems:

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

South Victorian Coastal Plains

8.4 Fans and Terraces – Western Port

8.5 Barrier Complexes – Discovery Bay, Gippsland Lakes

South Victorian Riverine Plains

9.1 Present Flood Plain – Gippsland

With some:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

South Victorian Uplands

3.3 Dissected Fault Block – South Gippsland Ranges

Regolith: Generally thin, discrete spatial deposits of unconsolidated shell beds, sand, silt, and clay forming a complex three-dimensional regolith.

Annual rainfall: 650 mm to 1000 mm

Dominant mid-1800s vegetation type: Predominantly Sedgeland, Shrub, Woodland, Hedgeland, Rushland and Scrub with outskirts of Grassland, Woodland and Forest. Mangrove forests along the coastal shores.

Current dominant land uses: Urban and industrial development, rural residential development, coastal development, natural and man-made coastal waterways, conservation reserves, parkland, grazing, cropping, horticulture.

Mapping method: Outcrop geology and landform.

Right:

Mangrove environment on the saline (estuarine) mudflats at Cannons Creek.

Hydrogeology

Aquifer type (porosity): Unconsolidated sand, silt and clay with minor shell beds and gravels (primary porosity).

Aquifer type (conditions): Unconfined.

Hydraulic Conductivity (lateral permeability): Extremely variable. Probable range from 10^{-5} m/d to 10^{2} m/d, with clayey facies < 1 m/d; sandy facies up to 100 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 0.05 to 0.2.

Hydraulic gradient: Varies with landscape. Very low to low in swamps and backdune wetlands, and moderate in dunes.

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

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

Recharge estimate: Unknown, but would vary with the rainfall, landscape (soil-landform) and land-use at any location.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years. Extensive periods of soil waterlogging may add to local recharge.

Spatial distribution of recharge: Catchment wide with probable contributions from upward leakage from lower aquifers in places.

Aquifer uses: Limited, if any use. Most groundwater is extracted from the more productive aquifers at depth.

Salinity

Groundwater salinity (TDS): Generally in the range of 3,000 mg/L to 10,000 mg/L, but variable from fresh (<1,000 mg/L) to seawater (>30,000 mg/L).

Salt store: Moderate or high in swampy conditions.

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

Soil Salinity Rating: S1 to S3

Salt export: Wash off from surface.

Salt impacts: Mostly on-site. Some impacts off-site (eg. Bass River).

Risk

Soil salinity hazard: Moderate to high.

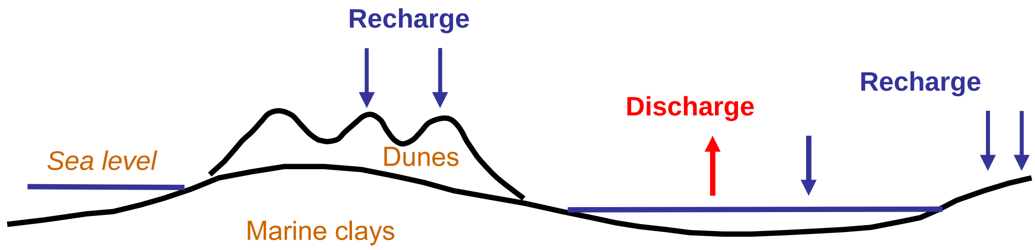
Water salinity hazard: Moderate to high.

Assets at risk: Urban and engineering infrastructure (Dromana), conservation wetlands and reserves (Warneet, Quail Island), water quality and aquatic biodiversity, agricultural land (Koo-wee-rup, Carrum Downs-Lyndhurst, Bass plain).

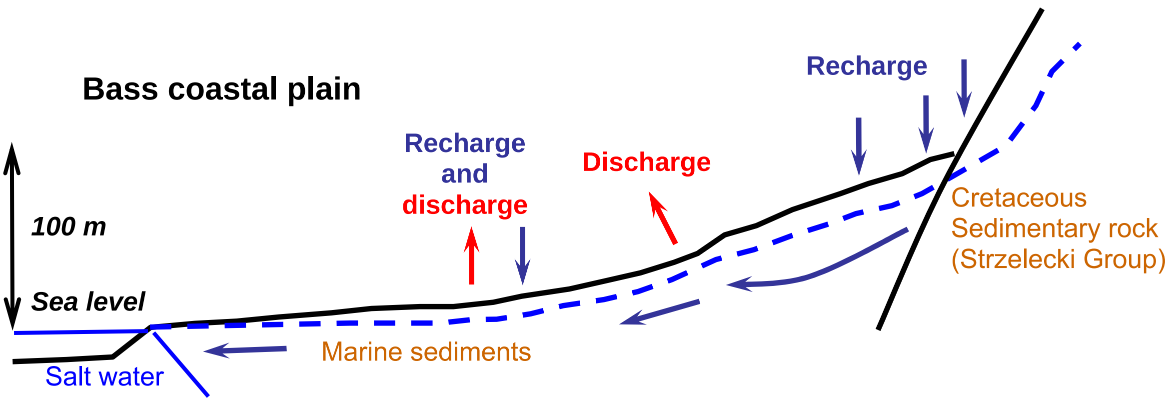
Responsiveness to land management: Varied, but generally should be very responsive. In both Koo-wee-rup and Carrum swamps the influence of deeper systems (vertical upward leakage) and the management of irrigation and groundwater resources (overpumping deeper aquifers) is more significant than land management on a seasonal or annual basis, so the response of the system to land management is low to moderate.

Conceptual models

Backdune wetlands



Bass coastal plain



Salinity (S1) on the Bass coastal plain

Management Options

Swamps impounded by dune sediments and estuarine plains are naturally waterlogged and primary saline (brackish) environments, formally dominated by Melaleuca and Mangrove vegetation. On the basis of their natural condition, it is unrealistic for waterlogging and salinity to be eliminated from these landscapes. Reintroduction of the salt tolerant indigenous vegetation may reduce secondary expansion of waterlogging and salinity. Unless properly managed, the regional influence of groundwater pumping from underlying aquifers may create problems in both the health of primary sites (drying of swamps) and secondary expansion of salinity (seawater intrusion contaminating aquifers).

A significant focus on land management in this GFS will be to maintain biodiversity values in the dune confined swamplands and coastal estuarine areas. Indigenous halophytic ecologies generally have a high conservation value, and are especially important in the larger estuarine wetlands of Port Phillip Bay and Western Port Bay.

Secondary salinisation tends to be low grade (e.g. S1 across the Bass Plains), so maintenance of healthy pastures (preferably with perennial habit) may somewhat limit seasonal waterlogging that exacerbates the development of soil salinity in these areas.

Dryland agriculture options for managing salinity in local flow in the **swamps and back-dune wetlands**

Salinity focus: Bass Plain, Tyabb East, Mt. Martha

Options	**Treatments**	**Comments**
Biological Management of recharge	Perennial pastures	Low impact– rainfall above 700 mm, some uncertainty in responsiveness
	Crop management	Low impact– generally not significant land use in these landscapes, and rainfall above 700 mm
	Trees/woody vegetation	Low to moderate impact– some potential for recharge and waterlogging control on plains/swamps, but requiring high density revegetation (unlikely)
Engineering intervention	Surface drainage	Low to moderate impact– Need to be sensitive to natural swampland health. Low topographic gradients for drainage. Disposal issues, though some areas could conceivably outfall to coast
	Groundwater pumping	Low impact– Need to be sensitive to natural swampland health, as well as impacts associated with possible incursion of seawater interface
Productive uses of saline land and water	Salt tolerant pastures	Low to moderate impact– Could be useful to stabilise secondary expansion, but care required so as not to introduce invasive species in sensitive areas
	Halophytic vegetation	Low to moderate impact– naturally adapted to swamps, estuarine plains
	Saline aquaculture	Low impact– not suited to local environs. Often low grade severity and relatively limited in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	Consider revegetating low lying areas with indigenous waterlogging and salt tolerant trees (e.g. Melaleuca). See OPUS database (NDSP)

Management implications given projected land use

Urban development pressures are significant along the Frankston – Mordialloc coast, including the salinity affected areas represented in this GFS (e.g. Mordialloc Creek). Where urban development does extend it may need to be engineered to withstand local conditions, and may need to be managed in a way to avoid applying additional hydrological loadings across the landscape. Depending upon the current and predicted future extent of the salinity hazard it may be preferable to limit infrastructure development in some areas.

In the Cannons Creek – Tooradin area the expansion of coastal and rural residential development ("lifestyle properties") needs to be carefully planned to avoid freshwater (stormwater and nutrient) loading on the primary saline mudflats which are a significant environmental asset.

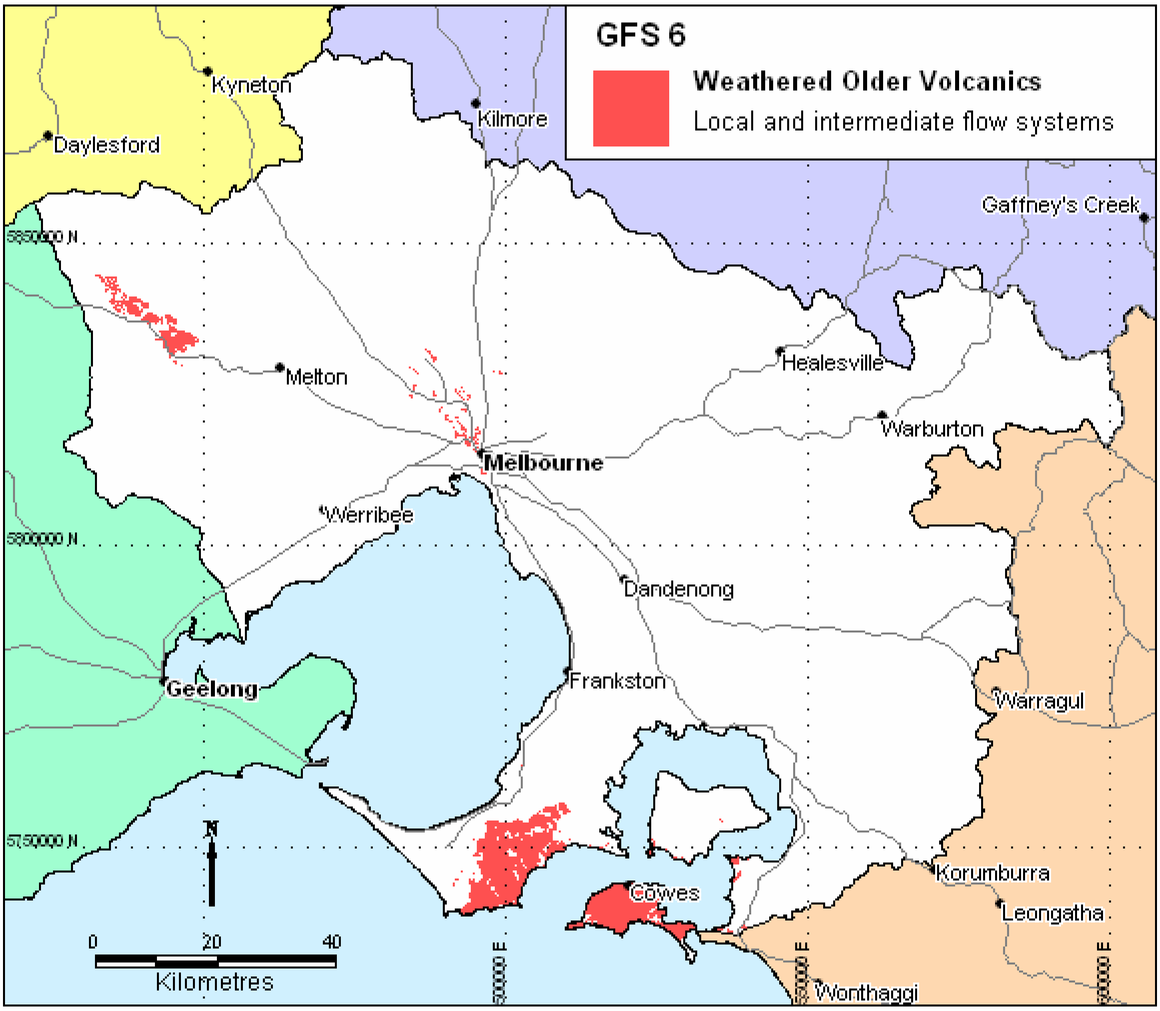
Salinity (primary) along the Mordialloc Creek (Wells Road Aspendale)

GFS 6 Local and intermediate flow systems in weathered Older Volcanics

Region: South eastern, central and western PPWP CMA region

Type areas: South east Mornington Peninsula, Phillip Island, Pentland Hills

Brief description: Sporadic volcanic eruptions commenced with the break-up of Australia and Antarctica during the Cretaceous and continued to almost the present day. The oldest of these eruptions (~ 60 Ma) formed basalts which were subsequently covered by Cainozoic sediments and later exposed by erosion in the Pentland Hills region. About 20 million years later voluminous eruptions during the Palaeogene formed extensive basalt deposits now exposed at Phillip Island and the south eastern region of the Mornington Peninsula. These have been grouped into one GFS on the basis of their similarity, being aquifers in which saline water is transmitted through the fractures of the weathered basalts in local flow and intermediate systems.



Problem statement: Over 1300 hectares of salinity associated with this GFS has been mapped on Phillip Island, and a small patch (~ 2Ha) at Flinders. The salinity has been associated with clearing of the native vegetation, although anecdotal accounts suggest that many of the saline areas were waterlogged (and may have been saline groundwater discharge areas) before widespread land-use change (Thomas & Bluml, 1992). Salts accumulate by evaporation of groundwater discharge into valley-floor alluvium. This process has probably accelerated since the disturbance of the natural ecology of the discharge zones.

Landscape attributes

Geology: Older Volcanic basalts (Tvo) and Quaternary alluvium (Qra)

Topography: Moderately dissected landscape with deep valleys (Pentland Hills), and rolling hills to undulating plains, with shallow valleys (Phillip Island).

Land Systems:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands – Midlands

Western Victorian Volcanic Plains

7.1 Undulating Plains – Western District

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

Regolith: Moderately weathered to completely weathered basalts, minor tuff and agglomerate. Slightly weathered to fresh, fractured basalt, at depth.

Annual rainfall: 550 mm to 1000 mm

Dominant mid-1800s vegetation type: Forest, Woodland and Scrub (minor Rushland)

Current dominant land uses: Predominately grazing, with expanding urban and rural residential development. Minor areas of waterways, parklands, urban and industrial development (Melbourne suburbs), with some horticulture and conservation areas.

Mapping method: Outcrop geology

Hydrogeology

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

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

Hydraulic Conductivity (lateral permeability): Probably less than 1 m/d.

Aquifer Transmissivity: Probably less than 20 m^2/d. A value of 1 m^2/d has been published from a test at Tullamarine (Shugg, 1975)

Aquifer Storativity: Less than 0.05.

Hydraulic gradient: Probably moderate to locally steep in valleys.

Flow length: 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. At Phillip Island, infiltration varies from >750mm/day to <7mm/day (Thomas & Bluml, 1992).

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

Spatial distribution of recharge: A map of “recharge” areas based on soil infiltration rates has been published (Thomas & Bluml, 1992). Higher infiltration rates were recorded on the cleared hills with loam soils. The relationship between infiltration and recharge has not been established. It is probable that recharge would be catchment wide in outcrop, with contributions from cross-formation flow at depth.

Aquifer uses: Minor. Mostly stock water.

Salinity

Groundwater salinity (TDS): Melbourne area 4,000 to 19,000 mg/L TDS. On Phillip Island salinity measured as EC indicates a range from < 500mg/L to 12,000 mg/L (600 μS/cm – 20,000 μS/cm).

Salt store: Low to moderate. A few local areas of high level salting recorded on Phillip Island.

Salinity occurrence: Valley floor, usually associated with the alluvium in waterlogged and poorly drained areas.

Soil Salinity Rating: Moderate. S1, S2, minor 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.

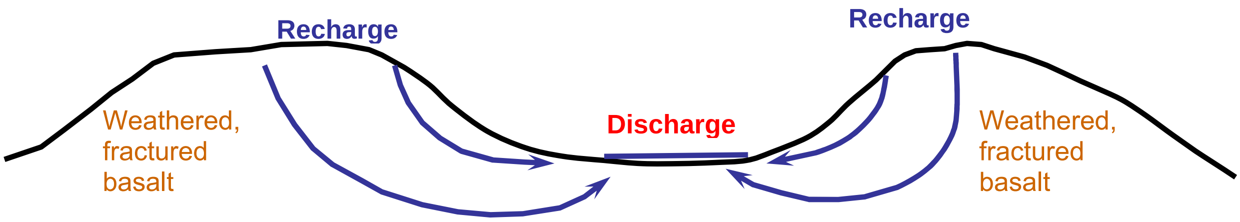
Water salinity hazard: High.

Assets at risk: Agricultural land (estimated increase of 20Ha/yr on Phillip Island), conservation areas and urban and road infrastructure.

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

Conceptual model

Weathered Older Volcanics (Phillip Island)



Salinity (S1) at Phillip Island

Management Options

Widespread salinity on Phillip Island is well documented and generally related to the natural waterlogging of the poorly-drained low-lying areas of the landscape. The salinity may be primary in part, since Melaleuca stands once dominated in these low lying areas, often characterised by waterlogged alluvial clays.

The replanting of the salt-tolerant, woody vegetation suited to the swampy conditions would likely control (but not remove) the expansion of salinity in the low lying salt prone areas. Effective management of salinity through recharge control is unlikely to be achieved given the natural landscape hydrology, and it would effectively require the re-establishment of broadscale wooded vegetation. Stabilisation of discharge sites and limiting run-on to these areas are considered more suitable treatment options.

Dryland agriculture options for managing salinity in local flow in the **weathered Older Volcanics**

Salinity focus: Phillip Island

Options	**Treatments**	**Comments**
Biological Management of recharge	Perennial pastures	Low to moderate impact– rainfall too high for significant impact from pastures alone. Perennial pastures offer a level of run-off and waterlogging and control
	Crop management	Low impact– generally not significant land use in these landscapes, and rainfall above 700 mm
	Trees/woody vegetation	Low to moderate impact– plantings where possible will assist in reducing run-off into waterlogged depressions, but effective recharge control would require mass planting (unlikely)
Engineering intervention	Surface drainage	Low impact– cost and disposal issues (waterway health) need to be considered.
	Groundwater pumping	Low impact– cost and disposal issues (waterway health). Low permeability alluvials and weathered basalt not conducive to high yield pumping.
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high impact– waterlogging tolerance required on alluvial flats.
	Halophytic vegetation	Low impact– climate not likely to be conducive
	Saline aquaculture	Low to moderate impact– there may be limited opportunities where there is sufficient groundwater, and where offsite salinity and nutrient issues can be managed
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	Consider revegetating low lying areas with indigenous waterlogging and salt tolerant trees (e.g. Melaleuca) See OPUS database (NDSP)

Management implications given projected land use

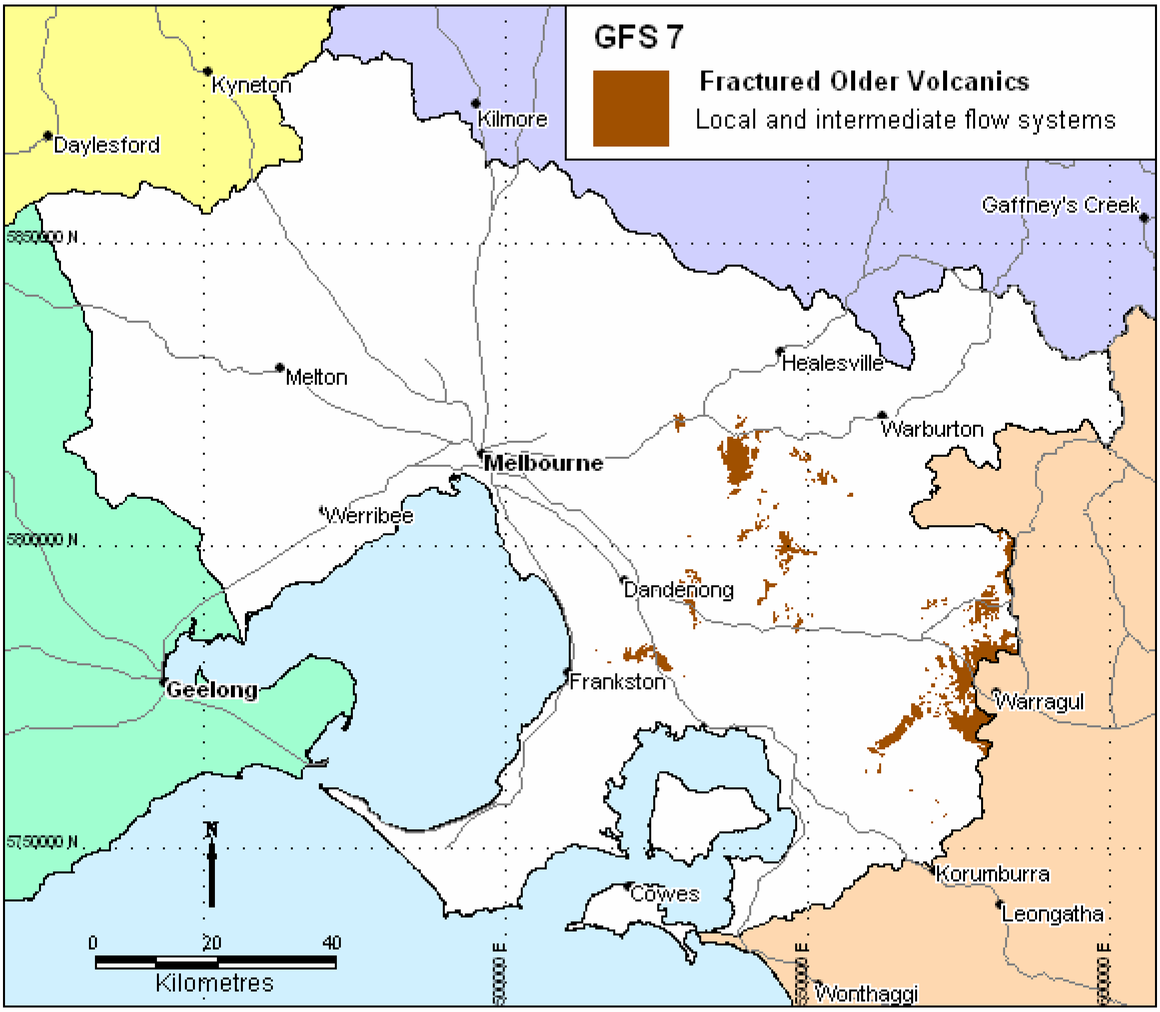
Planning for the expansion of urban development on Phillip Island needs to consider the significant areas of salinisation across the island. Where urban development occurs, or is planned, it may need to be engineered to withstand local saline conditions, and may need to be designed to avoid applying additional hydrological loadings across the landscape. Infrastructure development on the waterlogged alluvials needs to be minimised and designed to withstand the saline environment.

GFS 7 Local and intermediate flow systems in the fractured Older Volcanics.

Region: Eastern section of PPWP CMA region

Type areas: Silvan, Gembrook, Drouin, Jindivick, Cranbourne.

Brief description: At the commencement of the Neogene Period (~22 Ma), volcanic eruptions emplaced basalts of the Nerrim Sub-province and Melbourne Sub-province of the Older Volcanics. These basalts occur as relatively isolated caps on the Palaeozoic rocks exposed in outcrops, although along the eastern margin of the PPWP CMA region they dip eastwards under the Cainozoic sediments of the LaTrobe Valley.



Problem statement: No occurrences of dryland salinity have been mapped in this GFS. The groundwater in the fractured basalts of the Neerim Sub-province of the Older Volcanics is an important resource for irrigation particularly of market gardens and potato crops.

Landscape attributes

Geology: Older Volcanic basalts (Tvo)

Topography: Rolling hills and undulating plains.

Land Systems:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

3.4 Dissected Fault Block – South Gippsland Ranges

Regolith: Moderately to completely weathered basalt, minor tuff and agglomerate. Fresh to slightly weathered basalt at depth.

Annual rainfall: 600 mm to 1350 mm

Dominant mid-1800s vegetation type: Predominantly Forest with minor Woodland, Scrubland and Grassland

Current dominant land uses: Grazing, cropping, horticulture, urban and rural residential development, water supply catchment, conservation areas.

Mapping method: Outcrop geology

Hydrogeology

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

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

Hydraulic Conductivity (lateral permeability): Variable. Probable range of 10^{-3} m/d to 10^{2} m/d.

Aquifer Transmissivity: Weathered basalt at Silvan, up to 15 m^2/d (Shugg & Harris, 1975); higher in less weathered, highly fractured rock up to 725 m^2/d at Carrum Downs (Lakey, 1978).

Aquifer Storativity: Up to 0.15, but mostly less than 0.05.

Hydraulic gradient: Probably moderate to locally steep in valleys.

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

Catchment size: Small for local systems; intermediate systems probably depend on cross-formational flow.

Recharge estimate: Unknown. Probably 10% or more of rainfall.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years. Possible continuous leakage from connection with other aquifers at depth.

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

Aquifer uses: Irrigation of market gardens and horticulture Silvan-Wandin Yallock and Cranbourne-Mordialloc area; Golf club near Cranbourne and at Warragul (conjunctive with SW); stock and domestic.

Salinity

Groundwater salinity (TDS): Generally in the range of 500 to 1,500 mg/L

Salt store: Low.

Salinity occurrence: None mapped within this GFS.

Soil Salinity Rating: Low

Salt export: Low (if any)

Salt impacts: None known.

Risk

Soil salinity hazard: Low

Water salinity hazard: Low

Assets at risk: None known.

Responsiveness to land management: Should be relatively high, especially where the spatial distribution is limited (i.e. erosional remnant). May require careful groundwater resource management.

Management Options

There are no known land salinity issues to be managed.

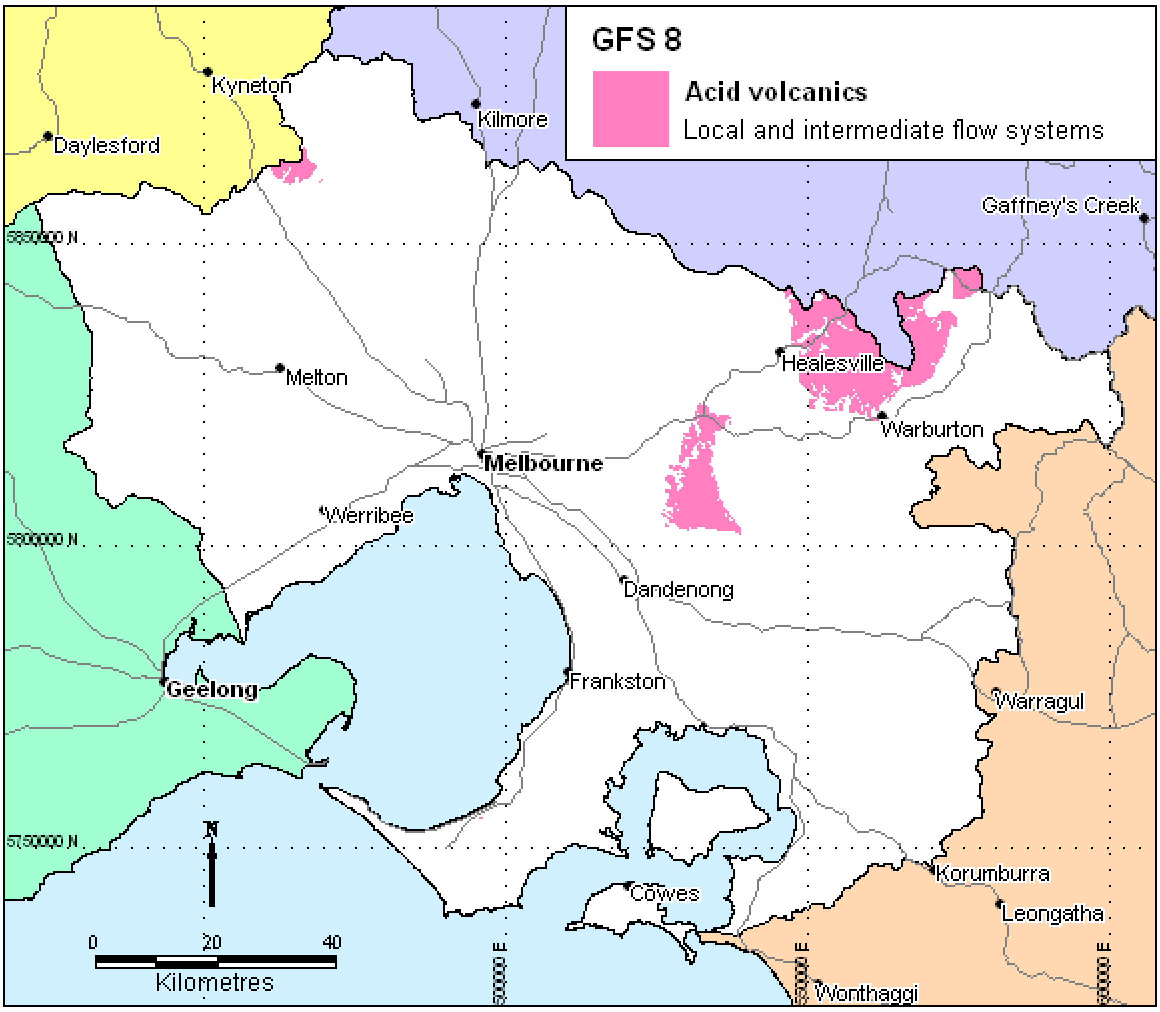
GFS 8 Local and intermediate flow systems in the acid volcanics

Region: Predominately north east PPWP CMA region

Type areas: Mount Evelyn, Belgrave, Mount Donna Buang, Mount Macedon

Brief description: Volcanic eruptions during the Late Middle to Upper Devonian Period (~370 Ma) emplaced a variety of acid volcanic rocks, mostly ignimbrites and rhyolites, in central Victoria. There rocks have been subsequently eroded to form many of the mountainous areas of the PPWP CMA region. The Dandenong Ranges, Macedon Ranges, and the Yarra Ranges.

Fresh groundwater flows through the fractured rocks in local and intermediate flow systems. Discharge often occurs as springs, which are the sources of many of the clear water mountain streams.



Problem statement: Salinity has not been mapped in this unit and is unlikely to be a problem.

Landscape attributes

Geology: Devonian Volcanics (Dvd, Dvc, Dvm)

Topography: Dissected ranges, ridges and valleys.

Land Systems:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands - Midlands

Regolith: Often shallow stony soils, and corestones surrounded by a silty clay matrix. Locally deep clay soils of completely weathered ignimbrite, or areas of rock outcrop (tors).

Annual rainfall: 800 mm to 1800 mm

Dominant mid-1800s vegetation type: Forest

Current dominant land uses: National Park and conservation areas, water supply catchments, rural residential and urban development, tourist developments, recreation developments (eg. snowfields) and parklands.

Mapping method: Outcrop geology

Hydrogeology

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

Aquifer type (conditions): Unconfined

Hydraulic Conductivity (lateral permeability): Low, probably less than 1 m/d.

Aquifer Transmissivity: Low, probably less than $10m^2/d$.

Aquifer Storativity: Low, probably less than 0.05

Hydraulic gradient: Moderate to steep

Flow length: Highly variable, from a few metres to several kilometres.

Catchment size: Generally less than 1000 Ha, but could be up to 5000 Ha.

Recharge estimate: Unknown.

Temporal distribution of recharge: Seasonal (winter and spring), with more in wet years. Some contributions from snowmelt during spring.

Spatial distribution of recharge: Catchment wide, but probably greater on the gentler upper slopes and plateaus.

Aquifer uses: Use is limited by low yields and very hard to drill aquifer.

Salinity

Groundwater salinity (TDS): Low (< 1500 mg/L)

Salt store: Low

Salinity occurrence: None known

Soil Salinity Rating: None mapped

Salt export: None known

Salt impacts: None known

Risk

Soil salinity hazard: Low

Water salinity hazard: Low

Assets at risk: None known

Responsiveness to land management: Not known (or applicable), however it should be rapid for local systems and moderate for intermediate systems.

Management Options

There are no known land salinity issues to be managed.

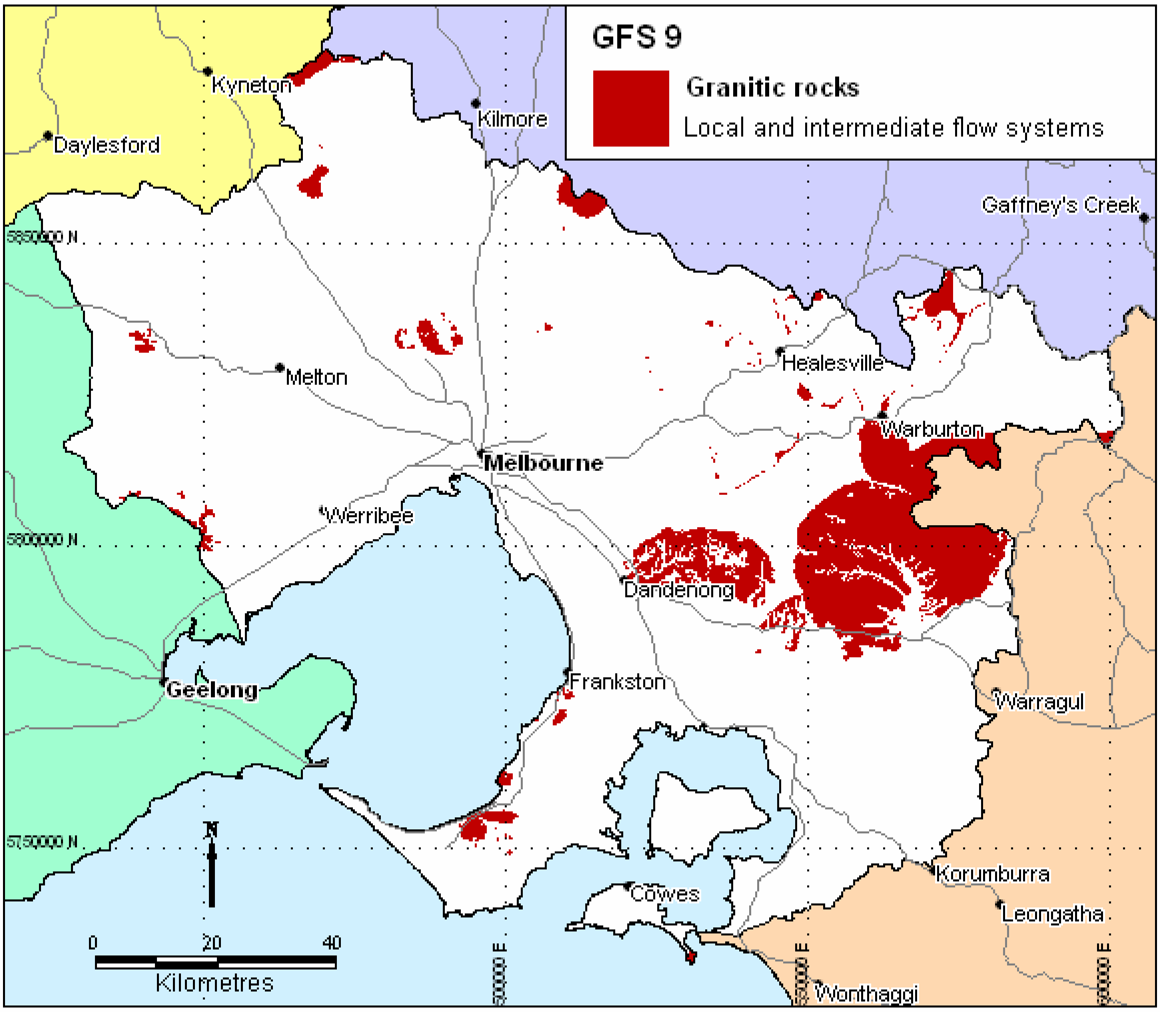
GFS 9 Local and intermediate flow systems in the granitic rocks

Region: All of PPWP CMA, with predominance in the east

Type areas: Powelltown, Dewhurst, Tynong North, The You Yangs.

Brief description: The granitic rocks in the PPWP CMA region were formed around 370 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.

Typically, sub-surface water movement in this GFS occurs through a variety of pathways and processes. Ephemeral fresh-water springs, usually following heavy or prolonged rainfall, are a feature of the landscapes where tors of granite are exposed at the surface. In areas with well-developed A_2 horizons in the soil profile, seasonal lateral flow is significant. In other areas where thick kaolin clays have developed (eg. Bulla), 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.



Problem statement: Small areas of salinity are mapped in the Bunyip, Garfield and Tynong areas near the junction of the granite with the Westernport plain (GFS 17). South of Balliang, severe salinity occurs along the edge of the granitic rocks of The You Yangs, although may not be greatly influenced by the flows in the granite (see GFS 2).

Landscape attributes

Geology: Devonian granites, granodiorites and adamellites (Dud, Dug)

Topography: Dissected ranges, rolling hills, undulating plateaus, isolated rocky hills.

Land Systems:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands - Midlands

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

Regolith: Highly variable, from fresh rock exposed at the surface (eg. Tynong North, Mount Disappointment); to sandy loams and sands (Powelltown); to extremely weathered regolith of thick kaolin clays (eg. Bulla).

Annual rainfall: 500 mm to 1750 mm

Dominant mid-1800s vegetation type: Predominantly Forest

Current dominant land uses: National Parks and conservation areas, urban and industrial development, grazing, cropping, water supply catchments, tourism and recreational developments.

Mapping method: Outcrop geology

Hydrogeology

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

Aquifer type (conditions): Unconfined where it is exposed in outcrop and semi confined in sub-crop.

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, although can be considerably higher in fractured zones.

Aquifer Transmissivity: Generally low, but may be up to 10 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: Generally low to moderate, but may be locally steep.

Flow length: Generally less than 5 kilometres, but individual pathways can be much longer.

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

Recharge estimate: Unknown and variable with location. Possibly up to 25 mm/yr or more in wetter landscapes.

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 (TDS): Generally in the range of 500 mg/L to 10000 mg/L.

Salt store: High where regolith is deeply weathered and thick.

Salinity occurrence: Minor occurrences along drainage lines and low-lying areas.

Soil Salinity Rating: S1, S2.

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

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

Risk

Soil salinity hazard: Generally low to moderate, but is high where the regolith is deeply weathered kaolin clay.

Water salinity hazard: Low to moderate.

Assets at risk: Agricultural land, urban and engineering infrastructure.

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

Granite landscape north of Lancefield.

Granite landscape at Tynong North

Management Options

The largest salinity issue occurs at Balliang, and the hydrogeological processes leading to its occurrence remain to be confirmed (refer to management options GFS 2). If the salinity processes can be modified by working on the granitic terrain, there would be significant opportunity for its management given rainfall is below 600 mm. However, the hydrological processes at Balliang have probably reached quasi-equilibrium, and the salinity may not expand significantly in the future. Substantial treatment programs are in place at the site and the cost - benefit of recharge control methods to ameliorate the discharge site need to be calculated and based on credible scenario models.

Smaller salinity discharge areas along the edge of the granitic bedrock east of Pakenham are perhaps more problematic given significantly higher rainfall and the potential for salinity issues to expand.

Dryland agriculture options for managing salinity in local and intermediate flow in the **granitic rocks**.

Salinity focus: Balliang, Bunyip, Garfield, Tynong

Options	**Treatments**	**Comments**
Biological Management of recharge	Perennial pastures	Moderate impact at Balliang– rainfall below 600mm. Soil fertility is a constraint to plant production, hence water use. Rehabilitate and improve grazing management of native grass pastures. Low impact east of Pakenham– rainfall above 700mm. Some contribution to run-off and waterlogging control
	Crop management	Low impact– generally limited cropping in these landscapes. Little or no benefit above 700 mm
	Trees/woody vegetation	Low to moderate impact– contribution to overall recharge (and runoff) control if trees incorporated into farming system. Impact dependent upon rainfall and scale of plantings.
Engineering intervention	Surface drainage	Low to moderate impact– disposal issues
	Groundwater pumping	Low to moderate impact– disposal issues. Pump sites possible in granitic colluvium.
Productive uses of saline land and water	Salt tolerant pastures	High impact– important to assist stabilising salt affected areas
	Halophytic vegetation	Moderate impact– species suited to temperate, moderately dry climate could provide ground cover on severely scalded areas (e.g. Balliang)
	Saline aquaculture	Low to moderate impact– apart from Balliang, discharge sites only small
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

Though the Balliang region is targeted as a zone for possible waste water re-use (irrigation), such developments will tend to occur on the higher quality soils of the adjacent basalt plains. As urban development stretches eastwards of Pakenham there will be issues for urban infrastructure in low lying discharge and waterlogged areas. Peri-urban development may present additional opportunities for controlling run-off and waterlogging, and to a lesser extent recharge.

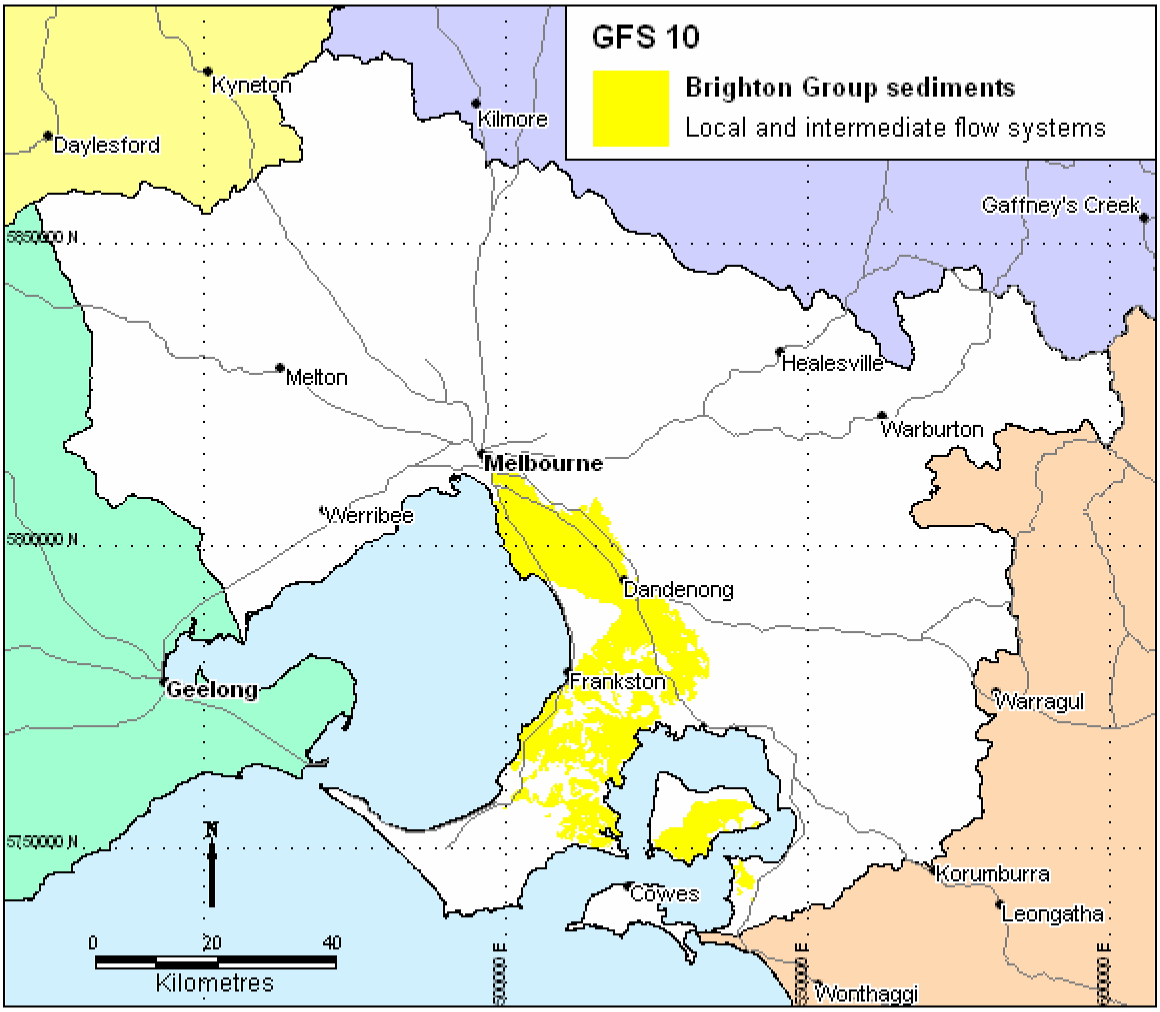
GFS 10 Local and intermediate flow systems in the Brighton Group sediments

Region: South central and south east PPWP CMA region

Type areas: Brighton, Dandenong, Tyabb, South eastern French Island

Brief description: The Brighton Group sediments (including the Baxter Formation in Westernport) form part of an extensive sand sheet that was deposited by a retreating sea during the Pliocene. The relatively thin veneer of gravels, sands, silts and clays layer is exposed in the south eastern Melbourne suburbs, the Mornington Peninsula and French Island. The Brighton Group also occurs beneath the basalts plain to the west of Melbourne with limited outcrop. Some overlying Quaternary age dune sands are grouped with this GFS on the basis that they are hydraulically connected and have similar hydrogeological characteristics.

The local flow systems occur where the sand forms isolated caps on dissected ridges, especially on the Mornington Peninsula. Intermediate flow systems may develop where the Brighton Group occurs as more extensive sheet-like deposits, such in the southeastern suburbs of Melbourne and parts of the Westernport Basin. Where the unit has been extensively ferruginised or silicified, the groundwater flow pattern can be locally distorted, resulting in shorter flow paths.



Problem statement: Salinity is associated with this GFS on the Mornington Peninsula, French Island and in the Corinella area. Primary salinity was probably a feature of these systems in some places. Land-use change has resulted in increased recharge and discharge through the local flow systems, resulting in an increase in salinity. Several conceptual models for salinity processes are possible, depending on the local geology.

Landscape attributes

Geology: Baxter Sandstone (Tpx) and Brighton Group (Tpb) sediments of Neogene age, Quaternary calcareous aeolian deposits (Qpd), aeolian dunes, dune sand and minor swamp deposits (Qrd), Quaternary alluvium (Qra), lagoon and swamp deposits (Qrm).

Topography: Undulating plains and local low ridges; dissected coastal plain; palaeo-strand lines.

Land Systems:

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

South Victorian Coastal Plains

8.3 Sands and Clay Plains - Moorabbin

8.4 Fans and Terraces – Westernport

8.5 Barrier Complexes – Discovery Bay, Gippsland Lakes

Regolith: Unconsolidated sand, silt and clay; ferruginous sand; calcareous sand; siliceous sand; ferruginous sandstone; occasional silcrete; minor gravels.

Annual rainfall: 650 mm to 950 mm

Dominant mid-1800s vegetation type: Predominantly Woodland but also areas of Scrub, Grassland, Forest and Rushland

Current dominant land uses: Urban and industrial development, grazing, horticulture, and conservation areas.

Mapping method: Outcrop geology

Right:

Salinity (S2, S3) on the Baxter – Tooradin Road, Pearcedale.

Left:

Salinity (S2, S3) at Gomms Rd, Somerville

Hydrogeology

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

Aquifer type (conditions): Unconfined to semi-confined

Hydraulic Conductivity (lateral permeability): Variable and largely unknown. Probably from 10^{-2} m/d to 10 m/d, with clayey facies less than 1 m/d and sandy facies 5-10 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 low (0.001) in intermediate systems to moderate or steep (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 25km 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. Recharge has been reduced by urbanisation in the southeastern suburbs.

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 18) on the plains.

Aquifer uses: Minor stock and domestic use.

Salinity

Groundwater salinity (TDS): Generally in the range of 500 mg/L to 7000 mg/L.

Salt store: Moderate to high.

Salinity occurrence: Drainage depressions (including lakes, swamps), low-lying areas, and at the boundary of the GFS.

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).

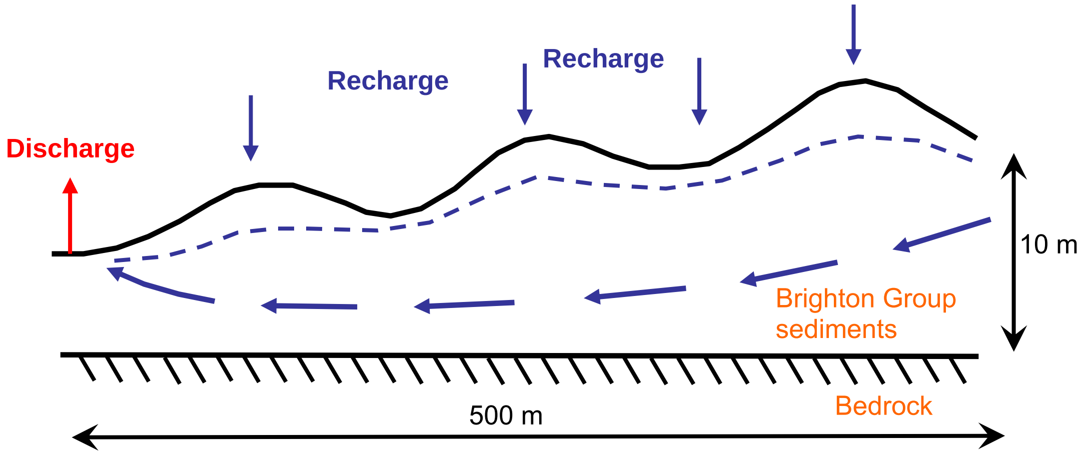
Water salinity hazard: Moderate.

Assets at risk: Engineering and urban infrastructure, conservation areas, agricultural land.

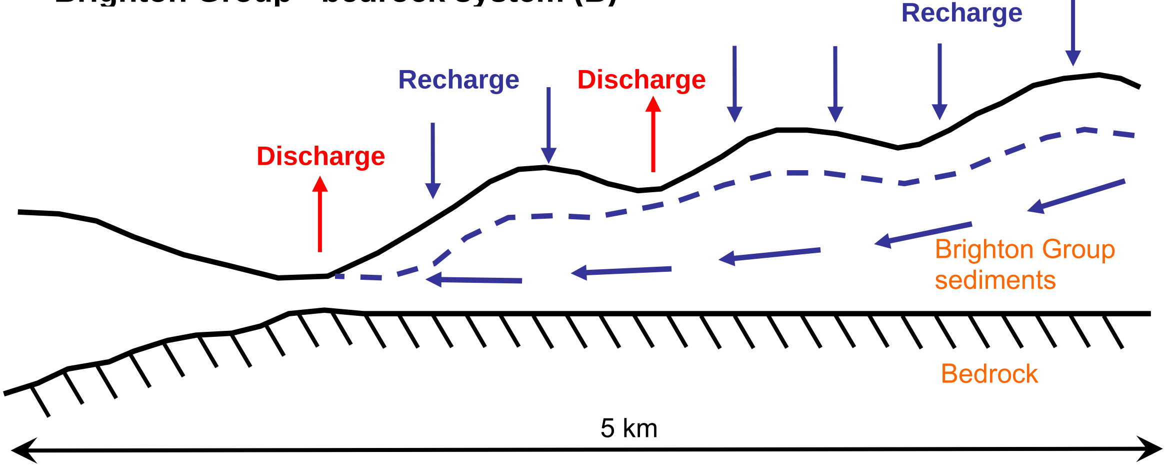
Responsiveness to land management: Largely unknown, but thought to be high for local systems and low for intermediate systems.

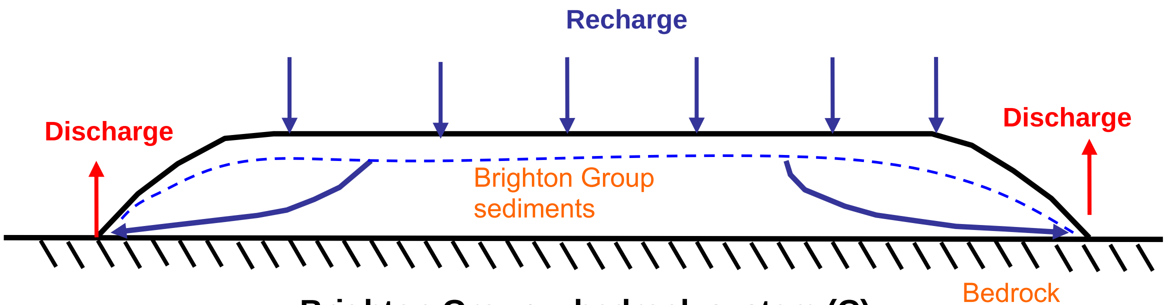
Conceptual models

Brighton Group - bedrock system (A)



Brighton Group - bedrock system (B)





Brighton Group – bedrock system (C)

Management Options

In places, salinity is a substantial issue within the Brighton Group sediments. Given the issue of intense urban encroachment and pressure for intensive agriculture, sitting on a landscape exhibiting locally high recharge rates (resulting in possible primary discharge pre-clearing), heterogeneous groundwater flow paths (cementing of sediments) and underlying bedrock influences on discharge, salinity management presents a significant challenge. In these circumstances it is unlikely that salinity can be significantly reduced, so that planning and engineering solutions will likely be required to avoid degradation of assets.

Dryland agriculture options for managing salinity in local and intermediate flow in the **Brighton group sediments**

Salinity focus: Mornington Peninsula, French Island, Corinella

Options	**Treatments**	**Comments**
Biological Management of recharge	Perennial pastures	Low impact– role of pastures in recharge control marginal, but productive pastures bring some run-off and waterlogging control benefits. Expanding urbanisation encroaching on grazed areas.
	Crop management	Low impact– cropping is generally absent in these landscapes
	Trees/woody vegetation	Low to moderate impact– inhibited by expanding urbanisation, but should be optimised in open spaces
Engineering intervention	Surface drainage	Low impact– disposal issues
	Groundwater pumping	Low to moderate impact– disposal issues. Consider in areas where specific asset protection is required. Some higher yielding, pumpable aquifers expected.
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high impact– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low impact– climate and environs not conducive
	Saline aquaculture	Low to moderate impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

On the Mornington Peninsula there are projected increases in urbanisation and intensive horticultural industries (e.g. vineyards) that will have significant implications for landscape hydrology. Under these circumstances, and given the nature of the salinity processes in the GFS, planning may preclude such developments in hazardous areas, and institute specific engineering standards for infrastructure to limit degradation potential.

Left:

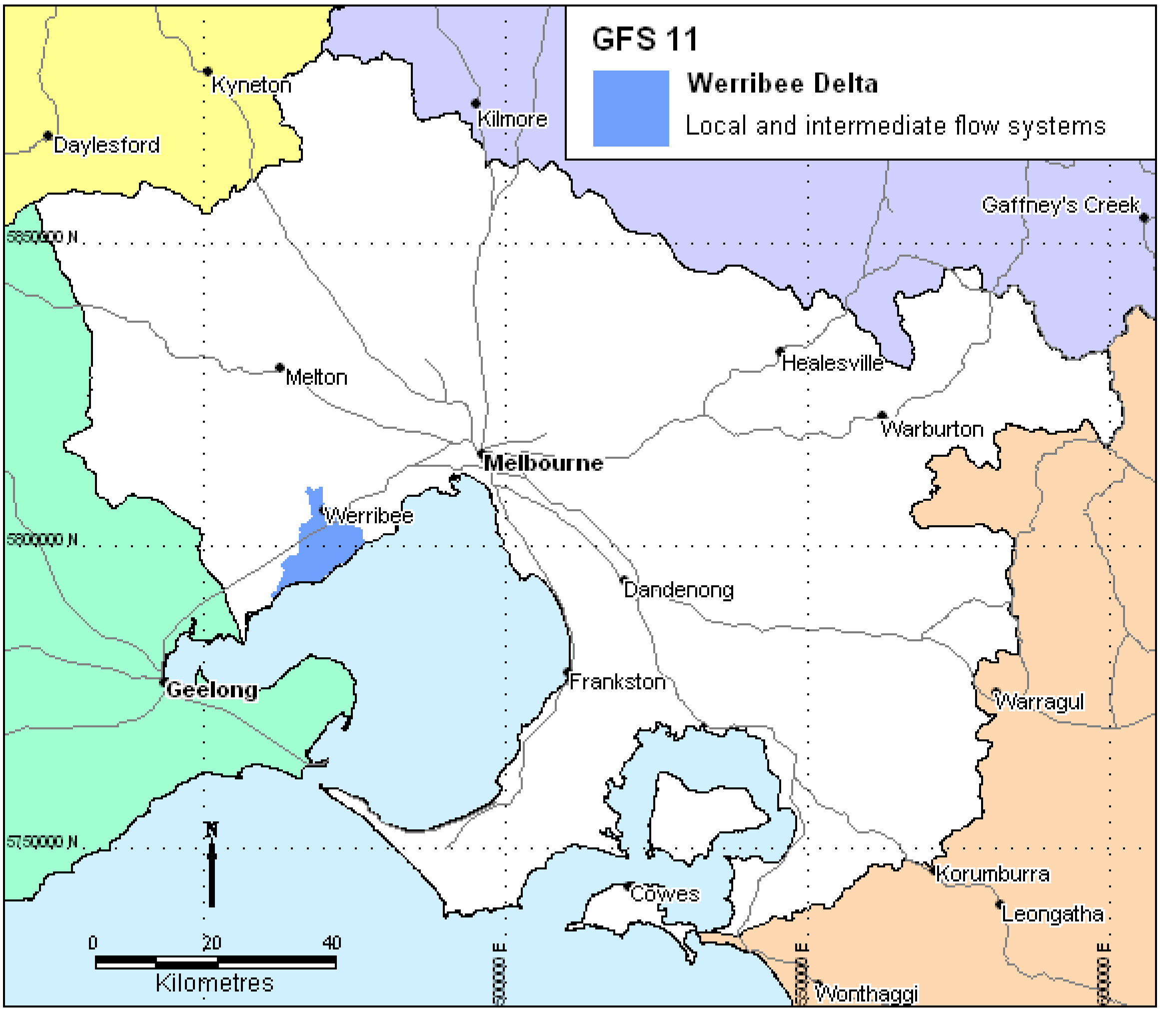
Saline discharge and iron precipitation, Bungower Rd, Moorooduc

GFS 11 Local and intermediate flow systems in the Werribee Delta

Region: South western PPWP CMA region

Type areas: Werribee, Werribee South

Brief description: The Werribee Delta has formed since the Pliocene by the accumulation of sediment carried by the Werribee River. Although of mixed provenance, the majority of sediments have been derived from the erosion of the Rowsley (Parwan) Valley (refer to GFS 12) over the past 4 million years. The sediments form a discrete GFS hydraulically connected to the underlying basalts (GFS 18) and Brighton Group (GFS 10).



Problem statement: The Werribee Delta GFS is one of the most challenging groundwater management areas of Australia. Groundwater is used for irrigation supporting a major horticultural industry on the eastern portion of the delta (east of the Werribee River). The delta to the west of the Werribee River used for land treatment of sewage and has extensive sewage treatment lagoons. Connections to deeper aquifers, along with tidal and river influences complicate the hydraulics of the system. Salinity has been mapped adjacent to the lower Werribee River and on the western edge of the GFS. A proposed water re-use project has the potential to significantly impact on this GFS.

Landscape attributes

Geology: Quaternary flood plain deposits (Qpw), alluvium (Qra), colluvium and gully alluvium (Qrc) and lagoon and swamp deposits (Qrm).

Topography: Plain with minor undulations, river channel and estuary.

Land Systems:

South Victorian Coastal Plains

8.5 Barrier Complexes – Discovery Bay, Gippsland Lakes

Western Victorian Volcanic Plains

7.1 Undulating Plains – Western District

Regolith: Unconsolidated to weakly consolidated silt, sand and minor gravels. Large areas of disturbed ground and fill in the near-surface.

Annual rainfall: 500 mm

Dominant mid-1800s vegetation type: Predominantly Grassland with some Heathland and Woodland

Current dominant land uses: Urban and industrial development, sewage treatment lagoons, horticulture, government research station, conservation areas, recreational developments, part of government aviation base.

Mapping method: Outcrop geology

Irrigated horticulture, Diggers Road, Werribee South

Hydrogeology

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

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

Hydraulic Conductivity (lateral permeability): Extremely variable. Probable range from 10^{-6} m/d to 10^{2} m/d, with clayey facies less than 1 m/d and sandy facies 10 m/d to 15 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 0.01 to 0.1.

Hydraulic gradient: Very low to low (0.002), except around pumped wells.

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

Catchment size: Delta covers about 50 km^2. Groundwater catchments are smaller.

Recharge estimate: Estimated to be 5% to 10% of rainfall, with additional increments from irrigation.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years. Evidence of higher recharge during irrigation season.

Spatial distribution of recharge: Aerially distributed catchment wide direct rainfall infiltration recharge; enhanced local recharge under treatment lagoons; irrigation return and probable upward leakage from underlying aquifer.

Aquifer uses: Irrigation, predominately for market gardens, stock and domestic use from shallow bores.

Salinity

Groundwater salinity (TDS): Low. Generally in the range of 500 mg/L to 3000 mg/L

Salt store: Low.

Salinity occurrence: Low-lying area (river channel) adjacent to the lower Werribee River estuary at Werribee South (mostly primary), and a small area east of Little River.

Soil Salinity Rating: Moderate. S1, S2; some minor S3.

Salt export: Wash off from surface.

Salt impacts: Mostly on site, with some off-site impact on the lower Werribee River.

Risk

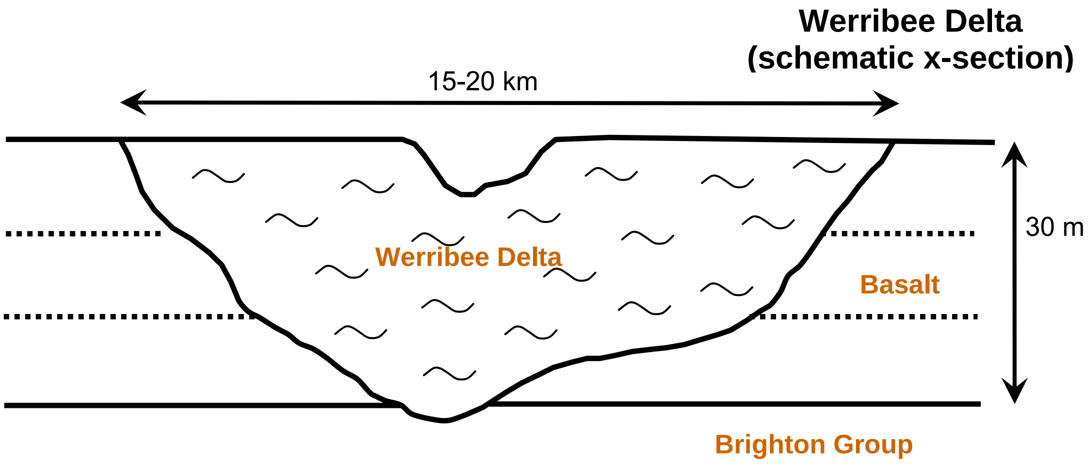
Soil salinity hazard: Low

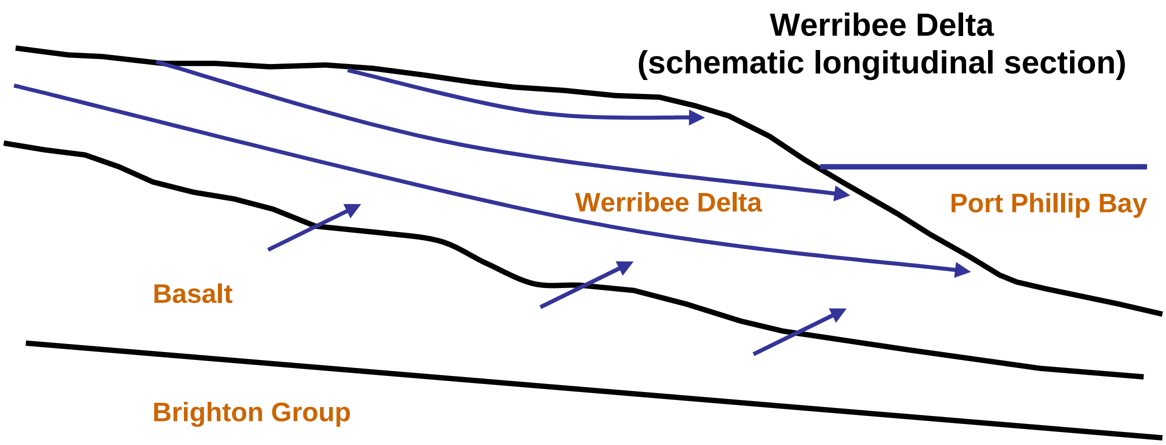
Water salinity hazard: Low

Assets at risk: Horticultural industry, urban and engineering infrastructure, water quality of the groundwater resource

Responsiveness to land management: Complex, since the influences of groundwater irrigation, sewage lagoons, tidal influences of Port Phillip Bay, groundwater-surface water interactions (eg. Werribee River), hydraulic connection to aquifers at depth and the impact of growing urban development are greater influences than traditional land management salinity solutions.

Conceptual model





Salinity along the alluvial flats adjacent to the Werribee River at South Werribee.

Management Options

At present, salinity is limited to the area adjacent to the river channel and is probably mostly primary salinity associated with the tidal influences in the estuary. Apart from stabilising these isolated salt affected areas, the significance and threat of salinisation is probably limited, given the intensive development of the delta. However, the irrigation, the sewage lagoons, the adjacent fixed seawater (and hence groundwater) head, and the convergence of groundwater flow from multiple aquifers, combine to create the potential for the development of salinity in the long term. In the shorter term, a significant management issue relates to protection of the beneficial groundwater resource residing in the delta sediments. In the longer term the continued application of irrigation water, both groundwater and recycled water, may accumulate salts in the soil through evapotranspiration.

Dryland agriculture options for managing salinity in local and intermediate flows in the **Werribee Delta**.

Salinity focus: lower Werribee River, western edge of GFS

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low impact– not likely to be applicable given current intensive land use regime
	Crop management	Low impact– not likely to be applicable given current intensive land use regimes
	Trees/woody vegetation	Low impact– not likely to be significant option given current intensive land use regimes
Engineering intervention	Surface drainage	Moderate impact– where surface waterlogging is as issue could outfall directly into Port Phillip Bay
	Groundwater pumping	Low impact– complex issue given current groundwater extraction and potential for seawater intrusion
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high impact– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low impact– climate and environs not likely to be conducive
	Saline aquaculture	Low impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

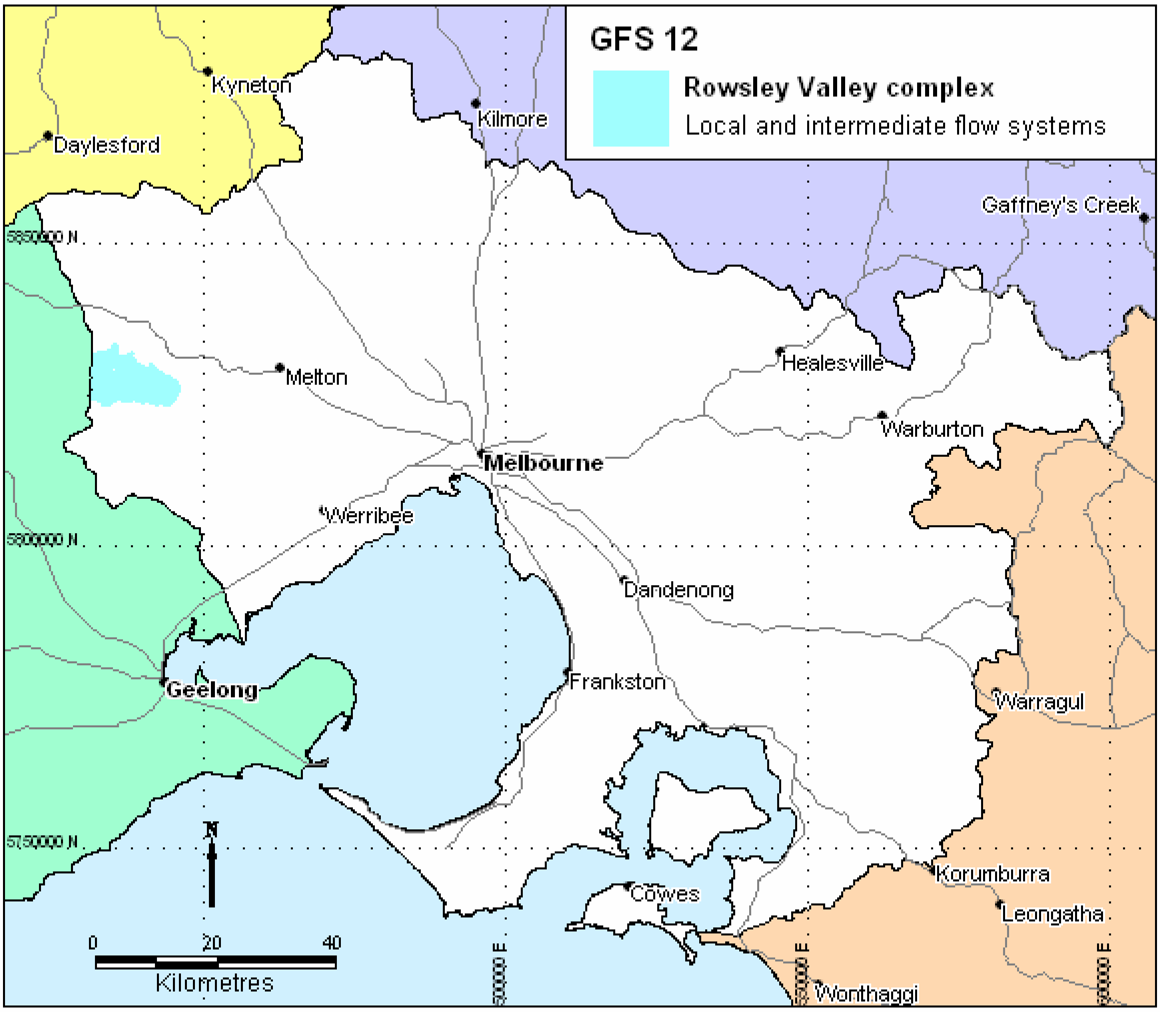
The current intensive land use regimes on the delta are likely to continue. Planning on the basis of land suitability should occur to optimise the placement of such developments in order for their own protection, and to limit potential salinity impacts on neighbouring developments.

GFS 12 Local and intermediate flow systems of the Rowsley Valley complex

Region: Western PPWP CMA region

Type areas: Rowsley, Glenmore, Yaloak Vale

Brief description: The Rowsley or Parwan Valley is a large 'bird's foot' valley incised into the Rowsley Fault scarp following uplift from the Pliocene to Recent. The Parwan and Yaloak creeks have cut through the basalts of the Newer Volcanics into the underlying Werribee Formation sediments. The rapid geomorphic development of the valley has resulted in some unusual landforms, including local mesas and isolated ridges. Landslides and erosion are features of the valley, resulting in significant areas of degraded land. The groundwater system of the valley is quite complex and a number of processes have been grouped together into one unique GFS.



Problem statement: Secondary salinity occurs in the valley floors and creek flats, probably as a result of land clearing and associated erosion of the valley floor. Spring discharge at the base of the basalt contributes to landslide processes and may contribute to the salinity. Groundwater in the Werribee Formation is probably confined by the boundaries of the Ballan Graben in which the valley is situated.

Landscape attributes

Geology: Ordovician Castlemaine Supergroup marine sediments of sandstones, siltstones, shale and chert (Ol, Olm). Permian fluvioglacial tillites of the Bacchus Marsh Formation (diamictites, sandstones, mudstones, conglomerates). Older Volcanic basalts (Tvo), Neogene alluvium (Tew, Tpb, Tpe, TRc) including the Werribee Formation, Brighton Group sediments and the Council Trench Formation. Quaternary alluvium (Qra, Qp2), colluvium and gully alluvium (Qrc), alluvial terraces (Qrt), lagoon and swamp deposits (Qrm), and Newer Volcanics basalts (Qvn) and scoria (Qvs).

Topography: Deeply incised undulating plain; steep slopes, isolated mesas and ridges, creek flats, undulating and hummocky low slopes, gorge.

Land Systems:

Central Victorian Uplands	Western Victorian Volcanic Plains
2.1 West Victorian Dissected Uplands - Midlands	*7.1 Undulating Plains – Western District*

Regolith: Highly variable. Unconsolidated cobbles, gravels, sands, silts and clays, weakly consolidated conglomerates, kaolin clay and sandy clay, ferruginised and silicified conglomerate and ironstone concretion boulders, thin bands of lignite, highly weathered basalt (sometimes with abundant calcium carbonate infill), scoria and pyroclastic sediments, palaeosols (sometimes with abundant pisoliths), and buried recent soil horizons.

Annual rainfall: 550 mm to 700 mm

Dominant mid-1800s vegetation type: Forest, Grassland and Woodland

Current dominant land uses: grazing, cropping, quarrying, educational and recreation facilities.

Mapping method: Outcrop geology

Hydrogeology

Aquifer type (porosity): Cobbles, gravels, sands, silts and clays (primary porosity), fractured basalt, ferruginised or silicified rock (secondary porosity).

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

Hydraulic Conductivity (lateral permeability): Variable and largely unknown. Probably from 10^{-2} m/d to 10^{2} 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 0.10

Hydraulic gradient: Highly variable, but generally associated with topography. Steep at the edges of the basalt, where springs occur. Moderate on the slopes and isolated ridges, low in the broad valley floors.

Flow length: Unknown. Possibly only a few metres to one kilometre in local systems, and up to 15 kilometres in the intermediate systems of the surrounding Werribee Formation.

Catchment size: Estimated to vary from very small (<1 Ha) in local systems to moderate (~ 5000 Ha) in intermediate systems.

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

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 20).

Aquifer uses: Minor use for stock watering?

Salinity

Groundwater salinity (TDS): Variable in the range from 500 mg/L to 10,000 mg/L

Salt store: Moderate to high

Salinity occurrence: Valley floor and creek flats

Soil Salinity Rating: S1, S2

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

Salt impacts: Both on-site and off-site

Risk

Soil salinity hazard: Moderate

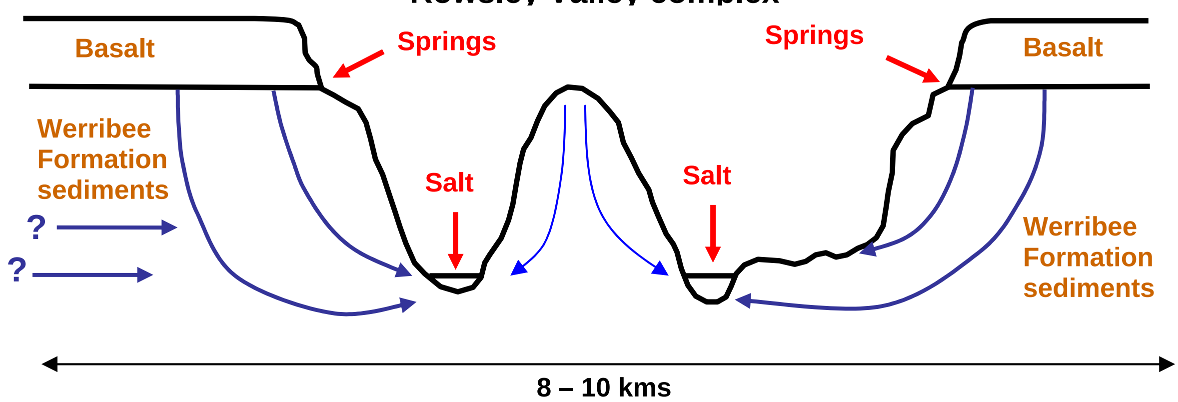
Water salinity hazard: Moderate

Assets at risk: Water quality of Werribee River (Melton Reservoir), agricultural land.

Responsiveness to land management: Complex. Needs varying solutions for different parts of the landscape. Should be high in local systems with short-path recharge-discharge.

Conceptual model

Rowsley Valley complex



Panoramic view of the Rowsley Valley from Cut Hill, Yaloak

Management Options

Salinity is a moderate issue in the Rowsley Valley. Practical salinity management is more likely where salinity discharge is related to internal valley local flow systems. However, intermediate (and perhaps regional) flow systems entering externally from the valley pose a greater challenge given the geographical extent of these systems. In these circumstances practicable salinity management will almost certainly revolve around stabilisation of discharge sites. Stabilisation of seeps is important to reduce the potential for landslips that emanate from spring zones along the base of the upper basalt cap.

Dryland agriculture options for managing salinity in local and intermediate flows in the **Rowsley Valley complex.**

Salinity focus: Rowsley Valley generally (e.g. Glenmore)

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Moderate impact– especially for reducing recharge in in-valley local flow systems. More problematic for intermediate flow systems emanating external to the valley.
	Crop management	Low to moderate impact– for treating in-valley local flow systems and incorporating perennial pasture phase (e.g. lucerne)
	Trees/woody vegetation	Low to moderate impact– for treating in-valley local flow systems where trees can be incorporated into overall farming system to reduce gross recharge
Engineering intervention	Surface drainage	Low impact– disposal issues
	Groundwater pumping	Low impact– cost and disposal issues
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low impact– climate and environs not likely to be conducive
	Saline aquaculture	Low impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

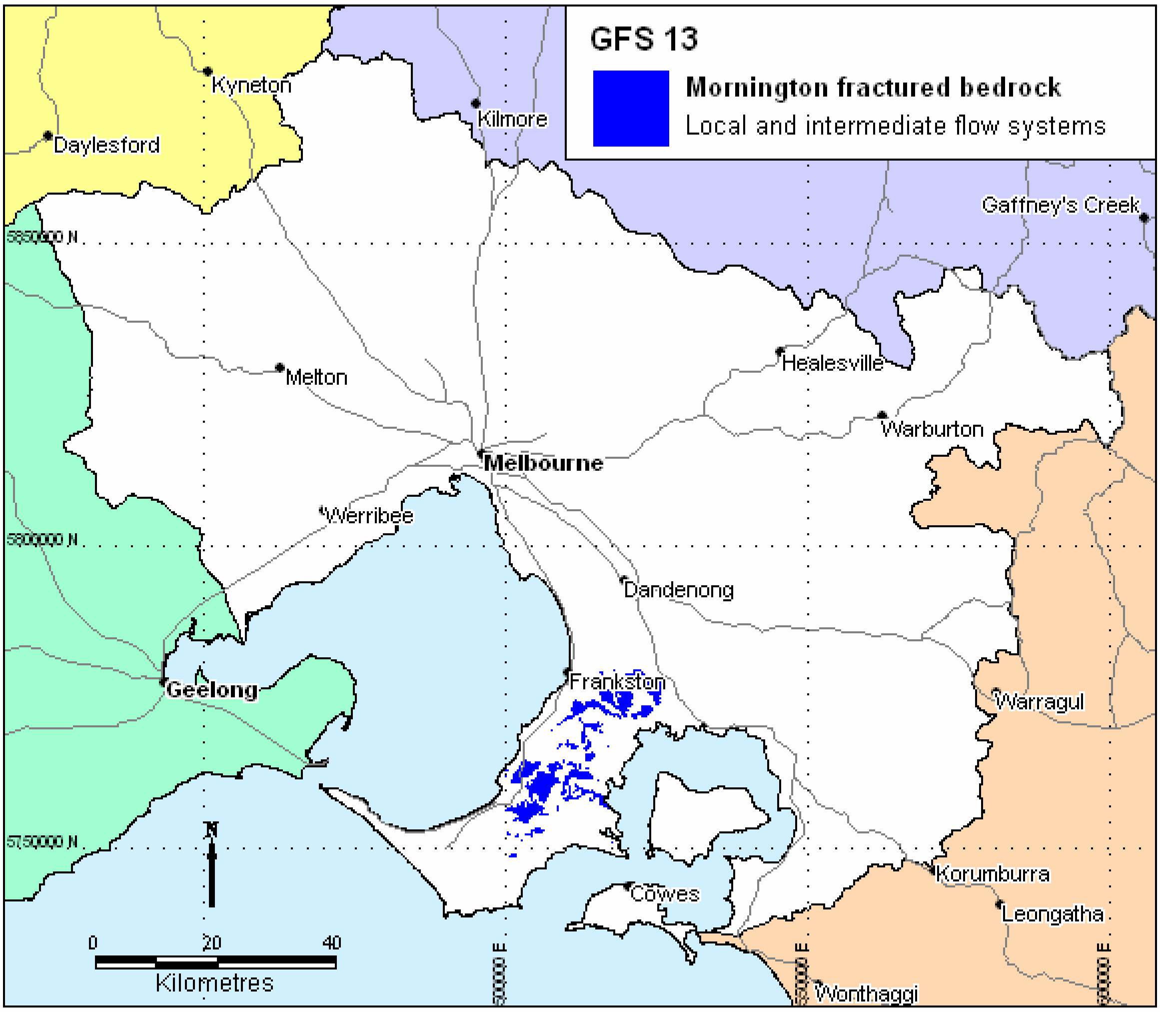
The current land use regimes within and surrounding the valley are anticipated to continue into the near future, though there will be periodical fluctuation in the ratio of dryland grazing to cropping. Raised bed cropping (and any associated irrigation practices) may become a hydrological/drainage issue on the basaltic soils west of the valley.

GFS 13 Local and intermediate flow systems of the Mornington fractured bedrock

Region: South central PPWP CMA (Mornington Peninsula)

Type areas: Bittern, Devon Meadows, Moorooduc South

Brief description: The underlying bedrock of the Mornington Peninsula comprises Ordovician and Silurian age sedimentary rocks (~ 480 – 420 Ma). Groundwater moves through the fractures in these sandstones and mudstones in local and possibly intermediate systems. The rock underlies the Brighton Group sediments (GFS 10) over most of the central Mornington Peninsula.



Problem statement: Small areas of salinity associated with this GFS have been mapped in the Devon Meadows, Langwarrin - Cranbourne South, and the Mount Martha – Safety Beach – Red Hill areas. In other areas, salinity in the Brighton Group sediments (GFS 10) and the Quaternary sediment (GFS 1) occur very close to the boundary with the bedrock. The salinity is probably associated with the altered hydrology following the massive changes in land use over the past century or more.

Landscape attributes

Geology: Ordovician and Silurian marine sediments: mudstones and sandstones (Ol, Ou, S).

Topography: Low hills and undulating plains.

Land Systems:

South Victorian Uplands

3.3 Moderate Ridge – Mornington Peninsula

Regolith: Highly weathered to completely weathered sandstones and mudstones.

Annual rainfall: 750 mm to 1000 mm

Dominant mid-1800s vegetation type: Forest, Scrub and Woodland

Current dominant land uses: Urban development, grazing, water supply catchment (Devilbend Reservoir), conservation area.

Mapping method: Outcrop geology

Salinity (S1) along a drainage line adjacent to the Nepean Highway, Mount Martha

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 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 low in intermediate systems and locally moderate in local systems.

Flow length: Generally <15 km for intermediate systems and <5 km for local systems.

Catchment size: Small (~<500 Ha) for local systems and moderate (>1000 Ha) for intermediate systems.

Recharge estimate: Unknown. Probably 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. Where covered by the Brighton Group sediments, continuous recharge would occur.

Aquifer uses: Minor use, mainly for stock water.

Salinity

Groundwater salinity (TDS): Generally in the range of 1000 mg/L to 8000 mg/L

Salt store: Moderate to high.

Salinity occurrence: Some within this GFS, but may contribute to salinity in the adjacent units (GFS 1 & GFS 12).

Soil Salinity Rating: S1 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: Low

Water salinity hazard: Moderate

Assets at risk: Streams and rivers, 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

High rainfall (in excess of 750 mm/yr), urbanisation and the relatively isolated instances of salinity will likely result in an emphasis on discharge treatment rather than significant recharge reduction. Salinity adjacent to the margins of this GFS appears more likely to be associated with groundwater flows terminating in neighbouring GFSs (GFS1 and GFS10).

Dryland agriculture options for managing salinity in local and intermediate flows in the **Mornington bedrock**.

Salinity focus: numerous occurrences across Mornington Peninsula

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low to moderate impact– rainfall too high for significant impact. Offers some level of run-off and waterlogging control.
	Crop management	Low impact– cropping is generally absent in these landscapes
	Trees/woody vegetation	Moderate impact– in local systems where they can be incorporated into existing land uses. Plantations and belts will reduce gross recharge, run-off, waterlogging
Engineering intervention	Surface drainage	Low impact– disposal issues
	Groundwater pumping	Low impact– low hydraulic conductivities make pumping expensive. Disposal issues
Productive uses of saline land and water	Salt tolerant pastures	High impact– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low impact– climate and environs not likely to be conducive
	Saline aquaculture	Low impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

On the Mornington Peninsula there are projected increases in urbanisation and intensive horticultural industries (e.g. vineyards) that will have significant implications for landscape hydrology. Under these circumstances, and given the nature of the salinity processes in the GFS, planning may preclude such developments in hazardous areas, and institute specific engineering standards for infrastructure to limit degradation potential.

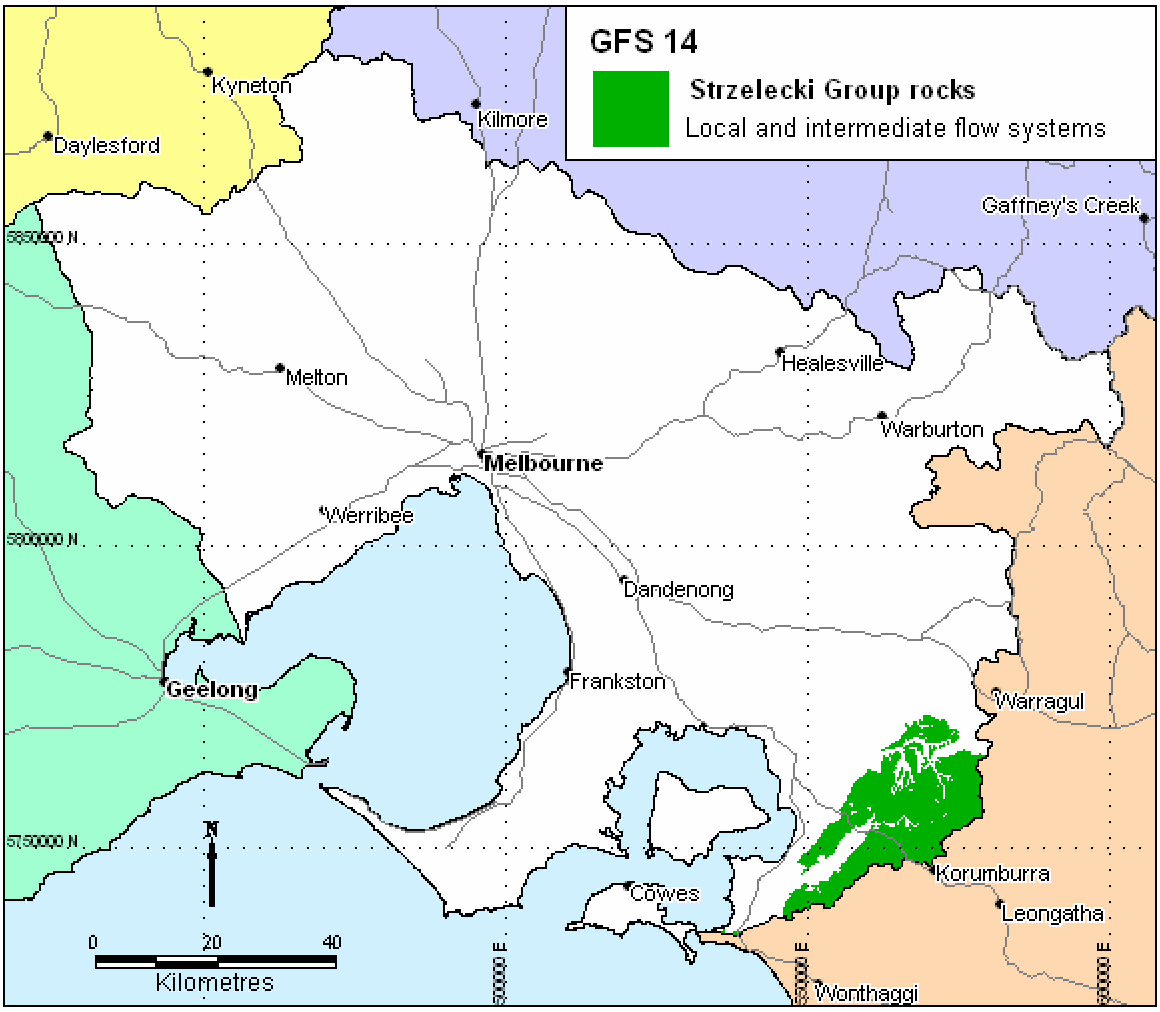
GFS 14 Local and intermediate flow systems of the Strzelecki Group rocks

Region: South eastern PPWP CMA region

Type areas: Loch, Poowong

Brief description: The lithic sandstone and mudstone rocks that make up the Strzelecki 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 Strzelecki Ranges since the Miocene has created deeply dissected landscapes with relatively thin soils.

Groundwater flows through the fractured rocks in intermediate and local flow systems, recharged by the high rainfall. The groundwater discharges into the streams of the Strzelecki Ranges from local and intermediate flow systems.



Problem statement: Current knowledge suggests that this GFS does not contribute to the salinity problem.

Landscape attributes

Geology: Strzelecki Group (Kls). Cretaceous fluvial lithic sandstones, siltstones, with minor conglomerates and coal.

Topography: Deeply to moderately dissected fault block, ridges and spurs, steep sided valleys.

Land Systems:

South Victorian Uplands	South Victorian Coastal Plains
3.4 Dissected Fault Block – Otway Range	*8.4 Fans and Terraces – Westernport*

Regolith: Skeletal to gradational soils over moderately weathered sedimentary rocks

Annual rainfall: 750 mm to 1100 mm

Dominant mid-1800s vegetation type: Predominantly Forest and Woodland with minor Rushland

Current dominant land uses: Grazing, dairy, forest, rural residential developments.

Mapping method: Outcrop geology

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 <10000 Ha.

Recharge estimate: Unknown. Possibly 100 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 (TDS): 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: Low

Water salinity hazard: Low

Assets at risk: None known

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

Management Options

There are no known salinity issues relating to this GFS to be managed.

Regolith profile of the Strzelecki Group rocks, South Gippsland Highway, Loch

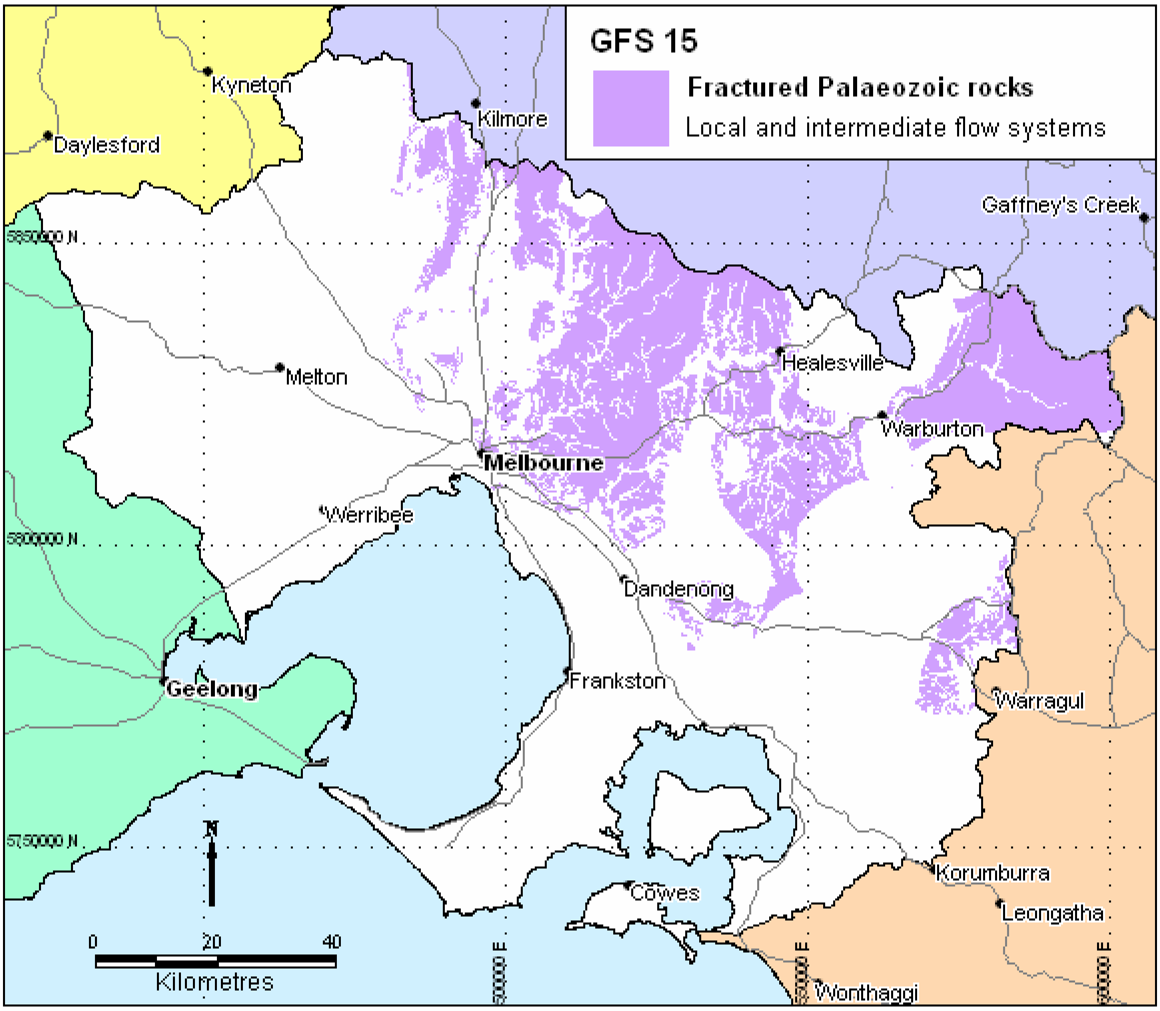
Strzelecki landscape, near Krowera.

GFS 15 Local and intermediate flow systems of the fractured Palaeozoic rocks

Region: Central and northern PPWP CMA region

Type areas: Doncaster, Hurstbridge, Whittlesea, McMahons Creek

Brief description: Sedimentary rocks of Silurian and Devonian age make up most of the hilly and mountainous areas north east of Melbourne. These folded and faulted sandstones, siltstones, shales, mudstones, conglomerates and limestones have been metamorphosed adjacent to the igneous intrusive rocks to form hornfels. Groundwater flows through the fractures in the rocks in local and intermediate flow systems. Local systems are more prevalent in the steeper terrains, whereas intermediate systems dominate the undulating landscapes.



Problem statement: Small outbreaks of salinity are associated with this GFS at the boundary with the Westernport plain (GFS 17) and the Volcanic Plain (GFS 18). In the Upper Yarra, the majority of the GFS remains as forested water supply catchments.

Landscape attributes

Geology: Silurian and Devonian marine sediments (sandstones, siltstones, shales, mudstones, conglomerates and limestones) (S, SDjg, SDl, Sla, Sld, Sls Sud, Suk, Sum, Dlc, Dlh, Dlwm, Dlwn, Dmk) and Devonian Hornfels (Duh)

Topography: Dissected uplands, ridges, spurs, hills and valleys.

Land Systems:

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands - Midlands

South Victorian Uplands

3.4 Dissected Fault Block – Otway Range

Regolith: Variable. Highly weathered sandstones and mudstones in the less steep terrain, and moderately to slightly weathered sedimentary rocks in the steeper terrain.

Annual rainfall: 600 mm to 1750 mm

Dominant mid-1800s vegetation type: Forest

Current dominant land uses: Urban and industrial development, water supply catchment, forests, conservation areas, rural residential developments.

Mapping method: Outcrop geology

Hydrogeology

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

Aquifer type (conditions): Unconfined and locally semi confined

Hydraulic Conductivity (lateral permeability): Variable from approximately 10^{-5} m/d 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 in the 0.02 to 0.05 range.

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: Possibly in the range of 50 mm to 100 mm annually. Could be considerably lower in suburban and industrial areas.

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

Spatial distribution of recharge: Catchment wide but varies with the depth of regolith, slope and land-use.

Aquifer uses: Minor use, mainly for stock and domestic purposes. Baseflow to streams is an important source of water supply.

Salinity

Groundwater salinity (TDS): Fresh to brackish. Generally less than 1500 mg/L, but could be up to 5000 mg/L.

Salt store: Low to moderate.

Salinity occurrence: Some small areas adjacent to the boundary with GFS 17 (Pakenham, Officer, Clyde North) and GFS 18 (Upper Maribyrnong River system), and GFS 1 (Upper Plenty River system)

Soil Salinity Rating: S1, S2

Salt export: Wash off from surface

Salt impacts: Both on-site and off-site

Risk

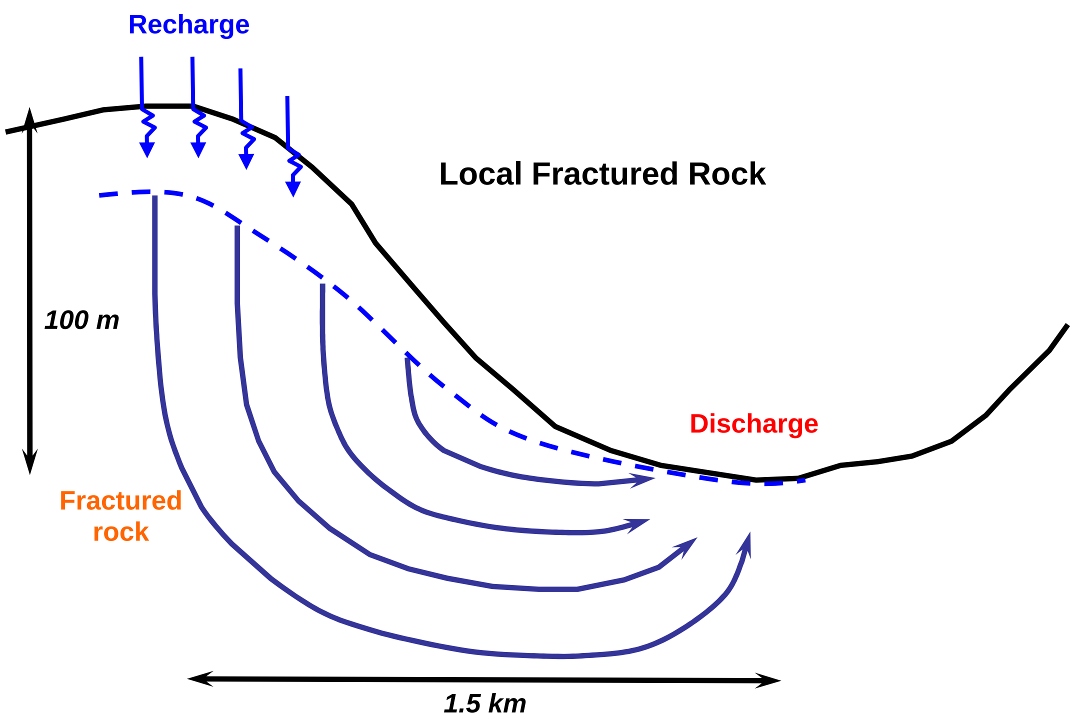
Soil salinity hazard: Low to moderate

Water salinity hazard: Low

Assets at risk: Water quality and aquatic biodiversity in Upper Maribyrnong and Upper Plenty river systems, agricultural land, urban development.

Responsiveness to land management: Unknown, but should be high for local systems and moderate for intermediate systems.

Conceptual model



Management Options

Isolated salinity issues are known to occur on the western and southern margins of this GFS. The extent to which groundwater flow through the fractured bedrock hills rising from the Westernport plain contributes to salinity on the plain (GFS17) and alluvial/colluvial sediments (GFS1) is unknown, but some level of impact is probable. On the western flanks of the GFS, the salinity may be partially related to groundwater emerging from thinning basalt (GFS 18), along the bedrock-basalt contact at the surface. Ultimately, management of salinity processes in this GFS requires a greater understanding of the hydrogeological relationship to the adjacent GFSs.

Where salinity can be directly related to flow processes occurring in this GFS, most solutions may practically reside with discharge management. Effective recharge control is limited by the slower response of intermediate flow systems and the generally moderate (>600 mm north of Melbourne) to high (>700 mm east of Melbourne) annual rainfall. In agricultural zones, maintaining perennial pasture health will at least assist in resisting runoff and associated waterlogging.

Dryland agriculture options for managing salinity in local and intermediate flows in the **Fractured Palaeozoic rocks**

Salinity focus: Pakenham footslopes, Clyde Nth, Upper Maribyrnong region

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low to moderate impact– rainfall too high for significant impact. Offers some level of run-off and waterlogging control.
	Crop management	Low impact– cropping is generally absent in these landscapes
	Trees/woody vegetation	Moderate impact– in local systems where they can be incorporated into existing land uses. Plantations and belts will reduce gross recharge, run-off, waterlogging
Engineering intervention	Surface drainage	Low impact– disposal issues
	Groundwater pumping	Low impact– low hydraulic conductivities make pumping expensive. Disposal issues
Productive uses of saline land and water	Salt tolerant pastures	High impact– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low impact– climate and environs not likely to be conducive
	Saline aquaculture	Low impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

Urban and peri-urban development pressures occur in the vicinity of this GFS both to the east (Pakenham corridor) and north (Whittlesea corridor) GFS. In these circumstances developments in areas contributing to salinity hazards should be planned to be generally sensitive to recharge and runoff control, and avoided where hazard is expressed in the landscape.

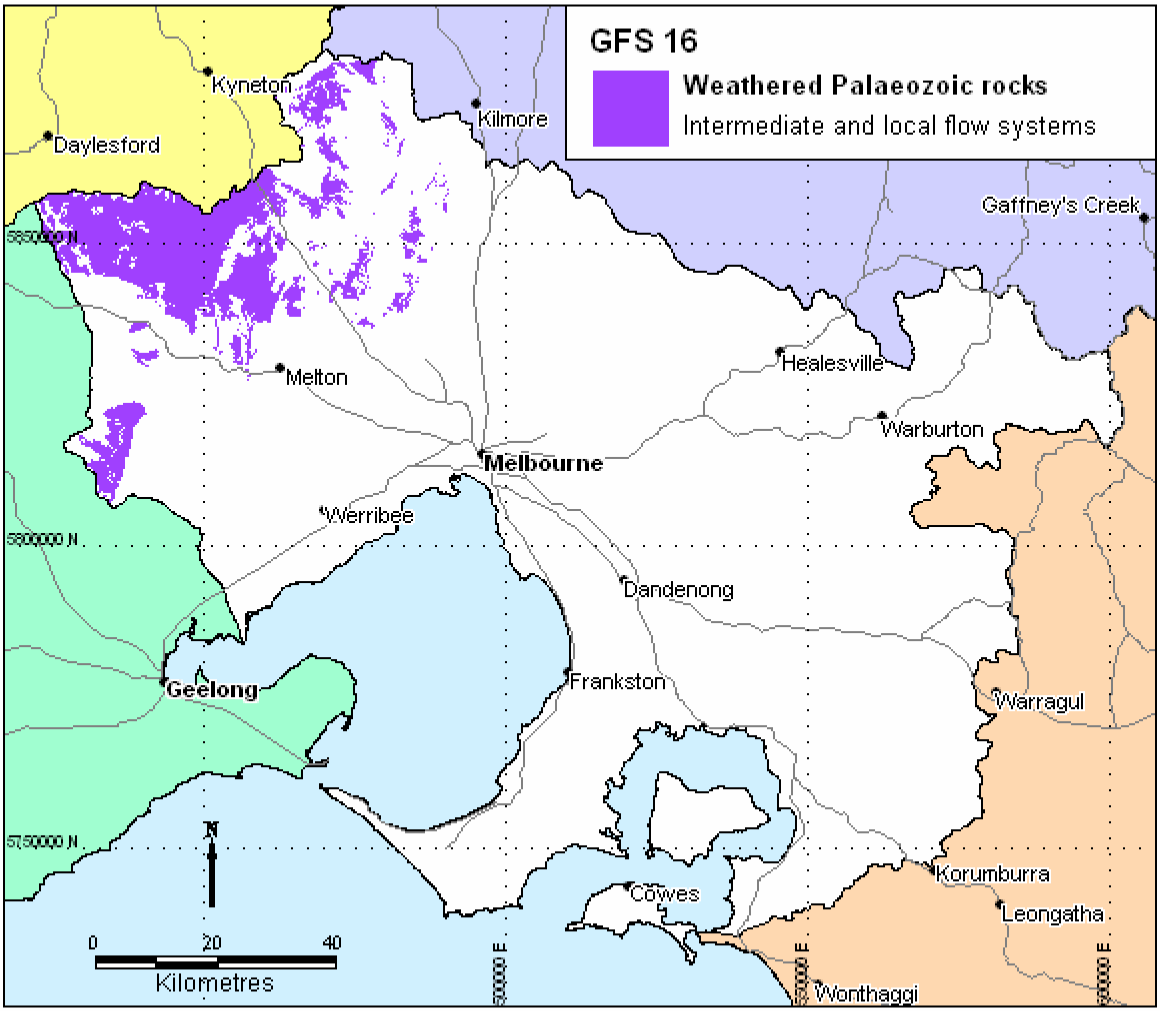
GFS 16 Intermediate and local flow systems in the weathered Palaeozoic rocks

Region: North west PPWP CMA region

Type areas: Gisborne, Toolern Vale, Blackwood

Brief description: Ordovician age sedimentary rocks make up the basement of the Western portion of the PPWP CMA region. These sandstones and mudstones 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.



Problem statement: Small areas of salinity are associated with this GFS in the Durdidwarrah – Steiglitz area, Cobaw – Newham area, and north of Riddell's Creek. The salinity generally occurs along drainage lines and probably results from hydrologic changes due to land clearing.

Landscape attributes

Geology: Silurian-Devonian Fluvial conglomerates, sandstones, and siltstones (SDk) and Ordovician marine sediments: sandstones, siltstones, shales, chert (Ol, Ola, Olb, Oll, Olm, Oly, Olr, Ou, Oub, includes Castlemaine Supergroup and Romsey Group).

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

Land Systems:

Central Victorian Uplands	Western Victorian Volcanic Plains
2.1 West Victorian Dissected Uplands - Midlands	*7.1 Undulating Plains – Western District*

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

Annual rainfall: 500 mm to 1200 mm

Dominant mid-1800s vegetation type: Forest with some minor Woodland

Current dominant land uses: Grazing, forestry, urban and rural residential, conservation areas.

Mapping method: Outcrop geology

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 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 (TDS): Generally in the range of 1000 mg/L to 8000 mg/L.

Salt store: Moderate to high.

Salinity occurrence: Creek lines, 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

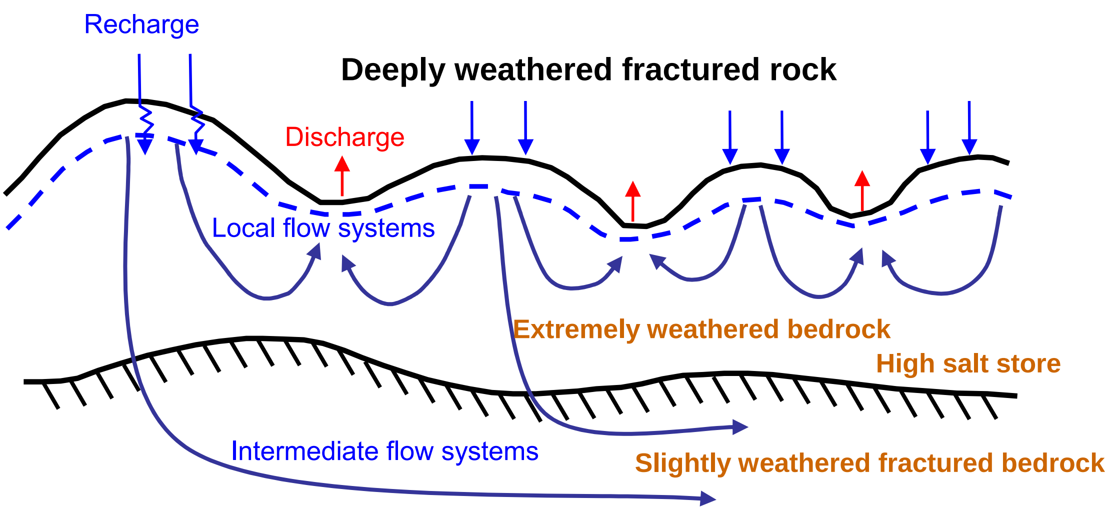
Soil salinity hazard: High.

Water salinity hazard: High.

Assets at risk: Water quality of the Upper Maribyrnong River system, agricultural land, engineering and urban infrastructure, conservation areas.

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

Conceptual model



Salinity (S1) developed in a tributary to Deep Creek, at Lancefield. The salinity occurs in a thin veneer of creek alluvium overlying the deeply weathered Palaeozoic sedimentary rocks.

Management Options

Salinity management strategies are required to address the development of salinity in the higher rainfall regime to the east of the Macedon Ranges, and the more moderate rainfall region of the Steiglitz-Durdidwarrah area at the southern end of the GFS.

The establishment of productive perennial pastures with opportunistic tree planting in cleared, lower rainfall terrain at Steiglitz-Durdidwarrah could be significant in reducing the extent of salinity discharge in localised flow systems.

Effective recharge control is limited adjacent to the Macedon Ranges by the higher rainfall, which approaches 700 mm/yr. In agricultural systems maintaining pasture health with perennial habit will at least assist in resisting runoff and associated waterlogging.

Dryland agriculture options for managing salinity in local and intermediate flows in **weathered Palaeozoic rocks**.

Salinity focus: Durdidwarrah-Steiglitz, Cobaw-Newham, Riddell's Creek

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low to moderate impact– depending upon climatic zone. Productive perennial pastures will at least assist with runoff and waterlogging control
	Crop management	Low impact– cropping is generally absent in these landscapes
	Trees/woody vegetation	Low to moderate impact– where able to be incorporated into overall land use system to reduce gross recharge, runoff and waterlogging
Engineering intervention	Surface drainage	Low impact– disposal issues
	Groundwater pumping	Low impact– low hydraulic conductivities make pumping expensive. Disposal issues
Productive uses of saline land and water	Salt tolerant pastures	High impact– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low impact– climate and environs not likely to be conducive
	Saline aquaculture	Low impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

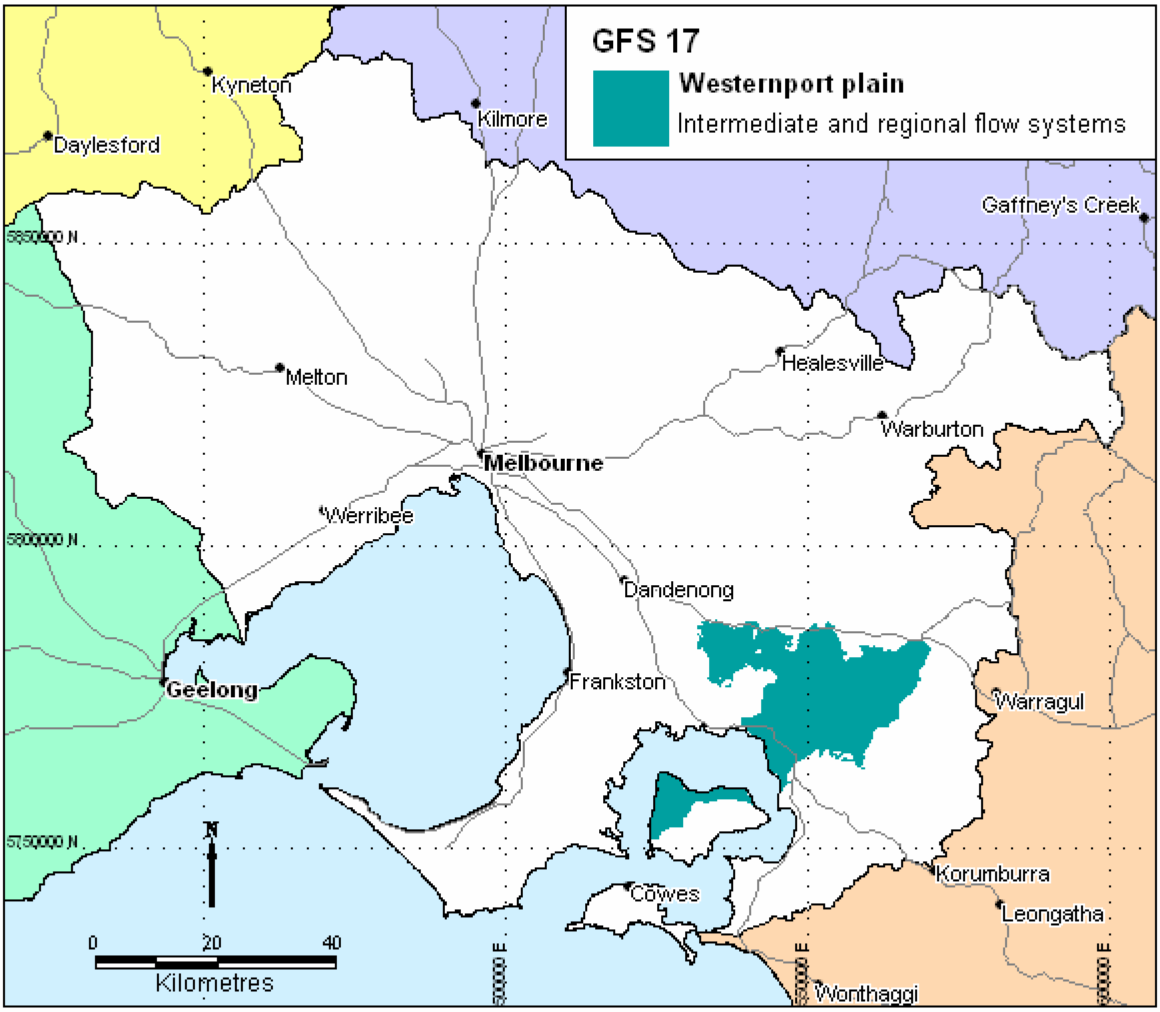
Pressure for rural residential development on this GFS at Riddell's Creek should be tempered with suitable planning guidelines. Responsible measures for reducing excessive recharge (and runoff and waterlogging) in both agricultural and rural-residential zones should be encouraged. Infrastructure development should be avoided where the salinity hazard is presented in the hazard.

GFS 17 Intermediate and regional flow systems of the Westernport plains

Region: South east PPWP CMA region

Type areas: Koo-wee-rup, Koo-wee-rup North, Modella

Brief description: The Westernport plains are underlain by a sequence of stratigraphic units of marine and alluvial origins. Groundwater moves through the various units and forms a complex three-dimensional system. The unit is hydraulically connected at depth to the French Island exposures of the GFS.



Problem statement: Groundwater extraction, tidal influences of Westernport Bay and cross formational flow between the aquifers at depth add to the complexity of salinity processes in this system. Small outbreaks of salinity have been mapped north and west of Cardinia and in the Nar Nar Goon area.

Right:

Irrigated horticulture (asparagus) at Koo-wee-rup

Landscape attributes

Geology: Quaternary flood plain deposits (Qpw), alluvium (Qra), aeolian coastal and inland dunes, dune sand and minor swamp deposits (Qrd), lagoon and swamp deposits (Qrm).

Topography: Plain, undulating plain

Land Systems:

South Victorian Coastal Plains	South Victorian Riverine Plains
8.4 Fans and Terraces – Westernport	*9.1 Present Flood Plain - Gippsland*

Regolith: Unconsolidated sand, silt and clay. Minor gravels.

Annual rainfall: 750 mm to 950 mm

Dominant mid-1800s vegetation type: Grassland, Rushland, Heathland and Scrub with minor occurrences of Forest and Woodland on the outskirts

Current dominant land uses: Grazing, horticulture, urban & rural development.

Mapping method: Outcrop geology

Hydrogeology

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

Aquifer type (conditions): Unconfined, with confined aquifers at depth.

Hydraulic Conductivity (lateral permeability): Extremely variable. Probable range from 10^{-5} m/d to 10^{2} m/d, with clayey facies < 1 m/d; sandy facies up to 100 m/d.

Aquifer Transmissivity: Variable, in the moderate range.

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

Hydraulic gradient: Generally very low to low, with moderate to locally steep gradients in the colluvium around the boundaries.

Flow length: Ranges from a few kilometres to >20 kms

Catchment size: Moderate (< 500 km^2)

Recharge estimate: Varies with the rainfall and landscape setting at any location.

Temporal distribution of recharge: Seasonal (winter and spring), with more recharge in wetter years. Irrigation and cross formational flow may contribute.

Spatial distribution of recharge: Catchment wide, with local irrigation mounds and contributions for deeper aquifers.

Aquifer uses: Irrigation, stock and domestic use.

Salinity

Groundwater salinity (TDS): Generally in the range of <1000 mg/L to 3000 mg/L.

Salt store: Moderate

Salinity occurrence: Secondary salinity occurs in low lying and flat areas, drainage lines, and swampy or waterlogged areas.

Soil Salinity Rating: S1, S2

Salt export: Wash off from surface.

Salt impacts: Mostly on-site. Some impacts off-site.

Risk

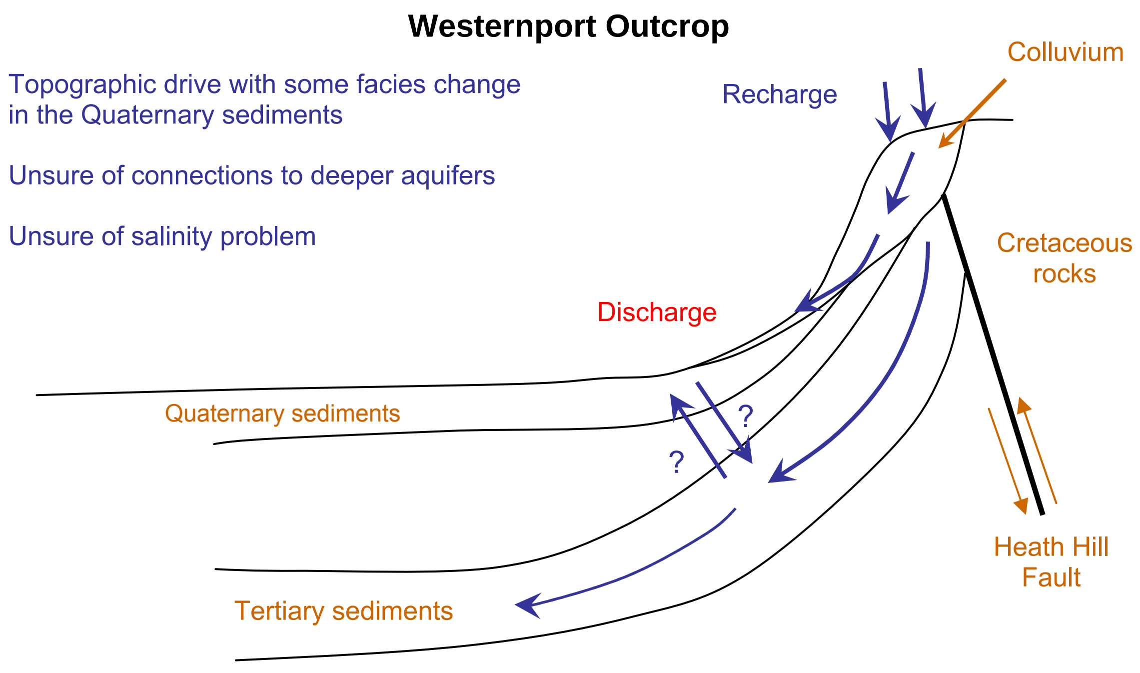
Soil salinity hazard: Low to moderate.

Water salinity hazard: Low

Assets at risk: Agricultural land, urban and engineering infrastructure, conservation areas.

Responsiveness to land management: Varied, but generally moderate. Groundwater extraction, irrigation, tidal influences and connection to underlying aquifers make the response to land-use change uncertain.

Conceptual model



Management Options

Given the interpreted original existence of grassy woodlands grading to Melaleuca and mangrove swamp progressively lower on the Western Port plain (and that the region abuts a permanent seawater head), generalised waterlogging and high watertables occurred naturally across the landscape. Land use change has likely exacerbated this condition, and probably led to local increases in soil salinity. On the basis of the natural condition, it is unrealistic to expect that waterlogging and elevated watertables can be significantly abated by any reasonable means.

The re-establishment of waterlogging and salt tolerant vegetation will assist in minimising the magnitude and period of waterlogging, and potentially maintain a sufficient unsaturated soil profile to allow leaching of shallow soil salt build-up. The long term prognosis for land management on groundwater salinities is unknown.
In some 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 Port Phillip Bay and Western Port Bay.

Dryland agriculture options for managing intermediate and regional flows on the **Westernport plain** **Salinity focus: Nar Nar Goon, Cardinia**		
Options	**Treatments**	**Comments**
Biological Management of recharge	Perennial pastures	Low impact– high rainfall and regional flow system. Salinity and waterlogging tolerance required
	Crop management	Low impact– cropping is generally absent in these landscapes
	Trees/woody vegetation	Low to moderate impact– plantings will assist in reducing the extent and duration of waterlogging and soil salt build-up. Effective recharge will require mass planting due to scale of the flow systems
Engineering intervention	Surface drainage	Low impact– shallow gradients an issue
	Groundwater pumping	Low impact– only low to moderate watertable aquifer permeability. Issues of disposal and subsidence. Specific asset protection only
Productive uses of saline land and water	Salt tolerant pastures	Moderate impact– salt and waterlogging tolerant pastures/grasses for stabilisation and aesthetics
	Halophytic vegetation	Low– poorly suited to climate
	Saline aquaculture	Low– may be limited opportunities where there is sufficient groundwater, and where offsite salinity and nutrient issues can be managed
	Salt harvesting	Low– groundwater is not sufficiently saline
	Others	Consider revegetating low lying areas with indigenous waterlogging and salt tolerant trees (e.g. Melaleuca). See OPUS database (NDSP)

Management implications given projected land use

The designation of the Pakenham plain as an urban growth corridor, with concentrated development of infrastructure, means that an adaptive approach to salinity and waterlogging will be required, though development ought to be avoided in the most hazardous areas. Developments should be designed and engineered to withstand shallow brackish watertables waterlogging and elevated soil salinity. Landscape hydrological modification that results in additional inputs to recharge and run-off loads ought be avoided. Further, the development of artificial water bodies need to be considered in respect to the additional hydraulic loads that they provide in the landscape, in relation to the barrier that they provide to surface and sub-surface drainage, and the impacts of leakage. There should be attention to prudent species selection in gardens, green areas and parklands.

Where there is additional horticultural development this should be sited in respect to land suitability and in relation to defined hazards. Additional excess recharge and waterlogging should be avoided by optimising the efficiency of irrigation applications.

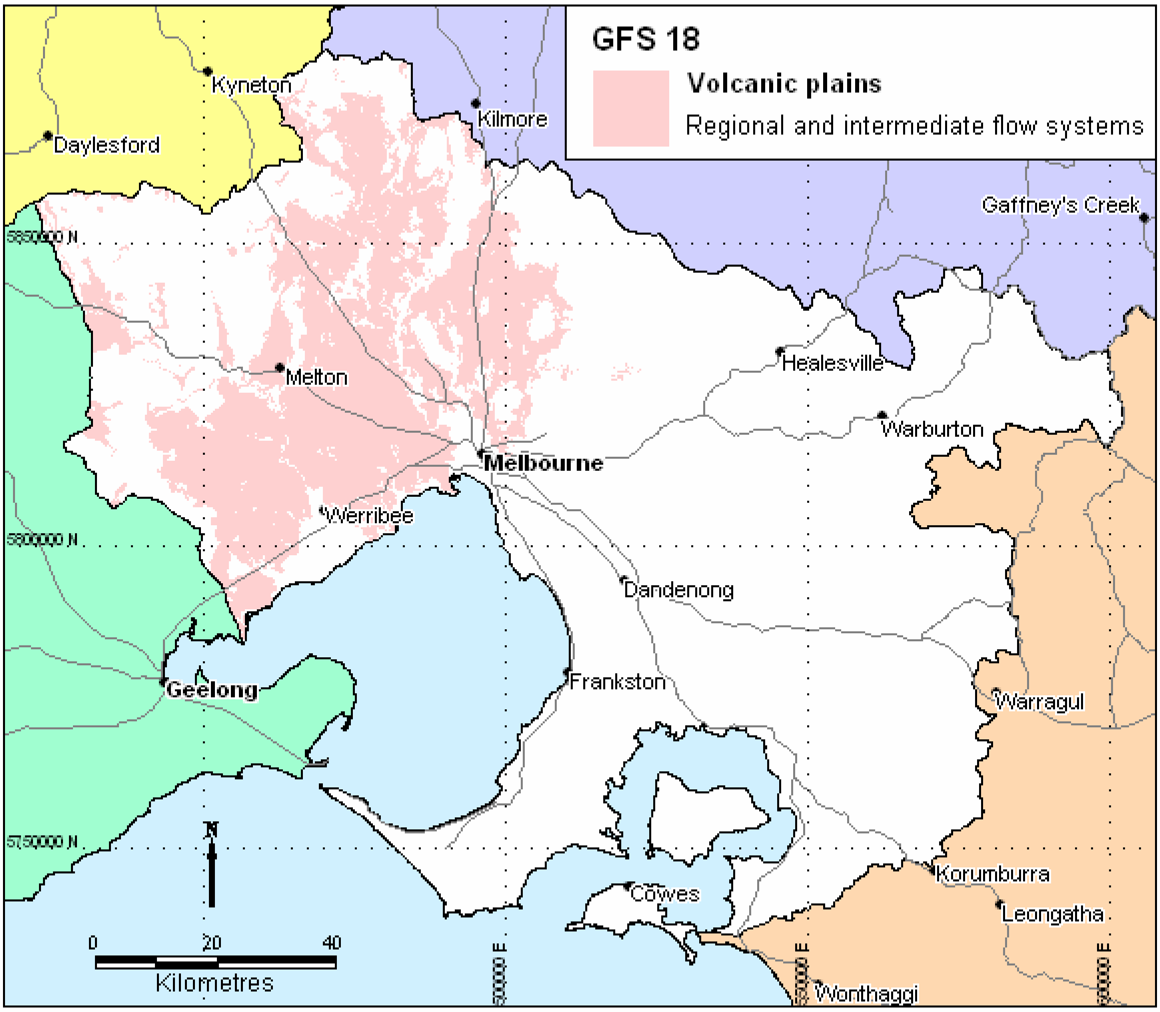
GFS 18 Regional and intermediate flow systems in the Volcanic Plains

Region: Western PPWP CMA region

Type areas: Melton, Rockbank, Donnybrook, Sunshine, Little River

Brief description: The basalt rocks in the western PPWP CMA region were formed by volcanic eruptions between 6 million and less than one million years ago. In the earlier phase eruptions, lava flowed over the pre-existing landscape, following drainage lines and spilling out across the coastal plains (GFS 10). The individual lava flows cooled to form lobes or tongues of basalt, generally less than 5 metres thick. Over the lengthy period of volcanic eruptions the overlapping lobes of basalt have built up to form the extensive basalt plains cover. In places, soils that had developed on the basalt were buried by the subsequent lava flows often several hundreds of thousand years later, now forming discontinuous confining layers in the basalt aquifer. The uppermost 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. Saline groundwater discharges in lakes, streams, swamps, and over broad depressions in the landscape.



Problem statement: In places, salinity and shallow watertables are natural features of this landscape. It is unclear how much hydrologic change there has been due to land-use change. Significant areas of salinity are mapped north of Rockbank.

Landscape attributes

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

Topography: Undulating plains and low rises, volcanic cones.

Land Systems:

Western Victorian Volcanic Plains

7.1 Undulating Plains – Western District

7.2 Stony Undulating Plains – Western District

Central Victorian Uplands

1.1 East Victorian Dissected Uplands

2.1 West Victorian Dissected Uplands - Midlands

Regolith: Varied. Duplex soils and heavy clay soil developed on weathered basalt of variable thickness, occasional scoria and pyroclastic deposit.

Annual rainfall: 500 mm to 1200 mm

Dominant mid-1800s vegetation type: Grassland, Woodland and Forest

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

Mapping method: Outcrop geology

Salinity (S2, S3) adjacent to Kororoit Creek, Leakes Road, Rockbank.

Salinity (S1, S2) along Kororoit Creek, Beattys Road, Rockbank

Hydrogeology

Aquifer type (porosity): Fractured rock (secondary porosity), scoria and 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 greater than10^{2} m/d (open fractures, scoria 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 than 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. Locally steep around volcanic cones.

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

Catchment size: Large (≤100000 Ha) for regional systems and moderate (≤5000 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 younger volcanic rocks and scoria.

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

Salinity

Groundwater salinity (TDS): 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

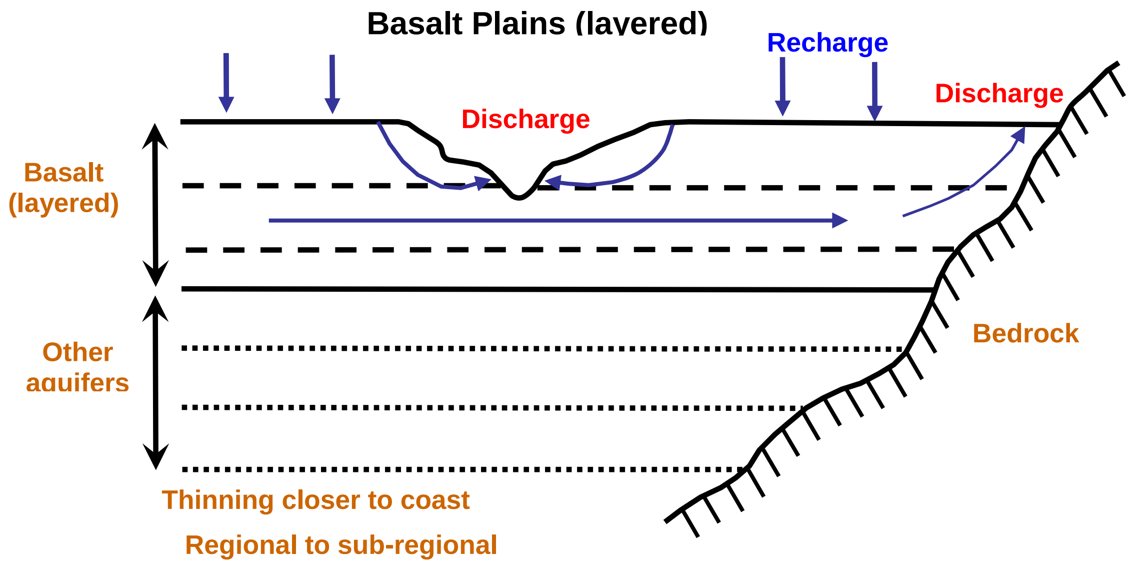
Soil salinity hazard: Uncertain, but thought to be high in some areas.

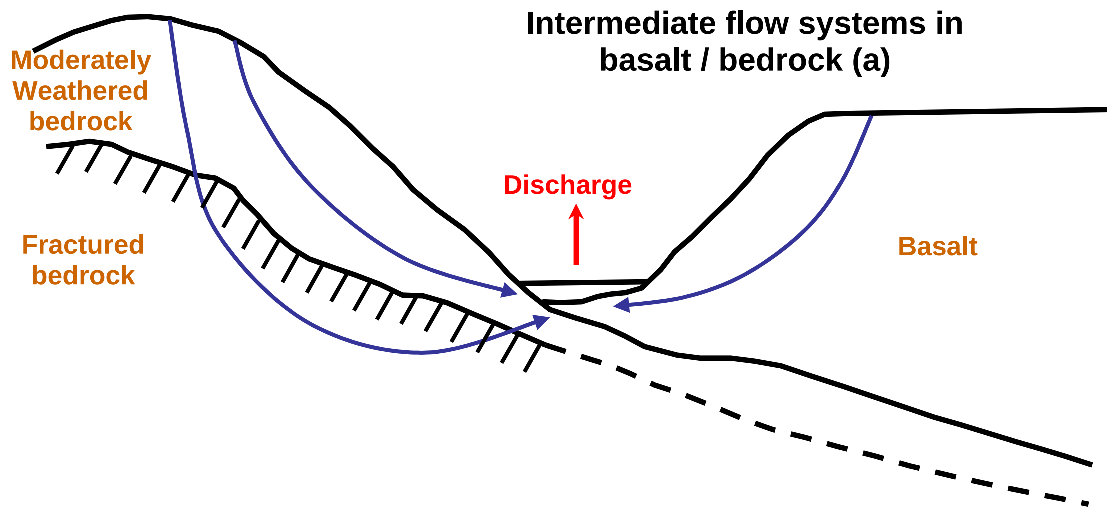
Water salinity hazard: High.

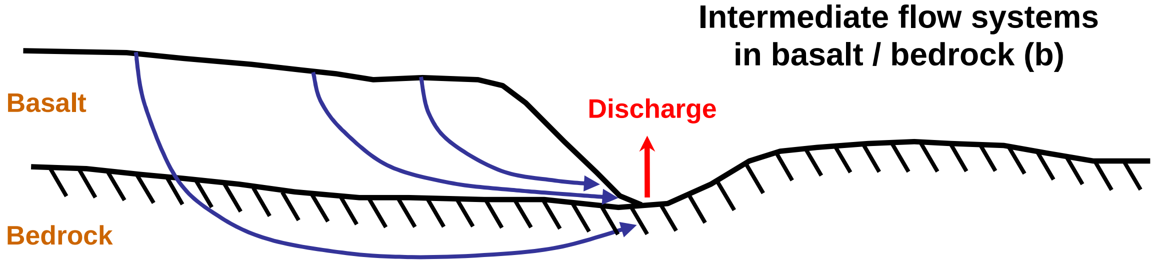
Assets at risk: Maribyrnong River, Merri Creek, Plenty River, Kororoit Creek, Werribee River, Little River, agricultural land, urban and engineering infrastructure, conservation areas.

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

Conceptual models







Management Options

On the Volcanic Plain salinity may be primary in origin, with expansion of the area affected due to secondary salinity exacerbated by modern land use change. Given that the vegetation of the early nineteenth century comprised grasslands and open woodlands, significant landscape recharge possibly occurred. Saline discharge was reported as seeps in depressions or occurring as baseflow into more deeply incised streams (assisted where basalt thins over bedrock). On this basis management strategies may somewhat control or reduce salinity discharge, but not eliminate it.

The regional nature and slow response of the flow system will inhibit significant impacts from practical recharge control strategies.

Dryland agriculture options for managing regional and intermediate flows of the **volcanic plains**

Salinity focus: Rockbank

Options	Treatments	Comments
Biological Management of recharge	Perennial pastures	Low impact– typically slow response, regional flow system. Productive perennial pastures will at least assist with run-off and waterlogging control
	Crop management	Low impact– as above
	Trees/woody vegetation	Low to moderate impact– where practical to incorporate into overall land use system to reduce gross recharge, runoff and waterlogging
Engineering intervention	Surface drainage	Low impact– disposal issues
	Groundwater pumping	Low impact– cost and disposal issues. Variable permeability makes pumping problematic. Specific asset protection only.
Productive uses of saline land and water	Salt tolerant pastures	Moderate to high impact– to stabilise and aesthetically improve salt affected areas
	Halophytic vegetation	Low to moderate impact– better suited in drier temperate zone
	Saline aquaculture	Low impact– discharge sites only minor in extent
	Salt harvesting	Low impact– groundwater is not sufficiently saline
	Others	See OPUS database (NDSP)

Management implications given projected land use

Salinity management strategies in the volcanic plains GFS will need to consider prescribed urban or industrial growth corridors, in addition to waste water reuse in the west. Both forms of development should be avoided in the defined hazardous areas. Where there is irrigation development this should be sited according to land suitability criteria. Additional excess recharge and waterlogging should be avoided by optimising the efficiency of irrigation applications.

References & Bibliography

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

ANON. 2000. Westernport Catchment Salinity Management Plan (Draft). Department of Natural Resources and Environment? December 2000, 22p.

CARRILLO-RIVERA, J.J. 1974. Hydrogeological maps of Western Port Basin, *Geological Survey Victoria Report* 55.

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., HEISLERS, D.S. & DYSON, P.R. 2000. Groundwater Flow Systems: Corangamite Catchment Management Authority region. Dahlhaus Environmental Geology Pty Ltd, consulting report CCMA 00/02.

DCNR (*undated*). A guide to dryland salinity in the north-west Yarra Catchment. Department of Conservation and Natural Resources. 24p.

EA 2004. Online database of Ramsar Wetlands in Australia. Environment Australia website, www.ea.gov.au

FETTER, C.W. 2001. *Applied Hydrogeology*. 4th edition, Prentice Hall, Upper Saddle River, NJ, 598p.

FORSTER, C., FUAUX, A. & GRAHAM, K. 1993. A preliminary assessment of dyrland salinity to the north east of Melbourne. Unpublished student report (Educational Institution not stated). 25p.

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

GILLESPIE, P. 1995. Report on watertable and salinity monitoring program, Phillip Island, 1991 – 1995. Department of Conservation and Natural Resources, May 1995, 36p.

HEISLERS, D.S. 1992. Groundwater in the Central Victorian Highlands. Water Division, *Department of Conservation and Natural Resources Report* Number 87.NLWRA 2001. *Australian Dryland Salinity Assessment 2000. Extent, impacts, processes, monitoring and management options*. National Land & Water Resources Audit. 129p.

HEISLERS, D.S. 1995. 1995 Community Groundwater monitoring report for the Corangamite Salinity Region: Geelong and Macedon sub-regions. *Centre for Land Protection Research Monitoring Report* No.4, August 1995.

HEISLERS, D.S. 1996. A technical appraisal of DNRE and community groundwater monitoring networks in the Corangamite Salinity Region. *Centre for Land Protection Research Monitoring Report* No.13, December 1996.

JENKIN, J.J. 1961. The Underground Water Resources of Phillip Island. *Underground Water Investigation Report* No. 1, Geological Survey Victoria.

JENKIN, J.J. 1962a. The Geology and Hydrogeology of the Western Port Area. *Underground Water Investigation Report* No. 5, Geological Survey Victoria.

LAKEY, R.C., 1978. A pilot study of groundwater recharge at Carrum using treated effluent. *Geological Survey Victoria Unpublished Report* 1978/56.

LAKEY, R.C. 1981. Evaluation of natural groundwater recharge in Western Port Basin, Victoria. In *Groundwater Recharge Conference, Proceedings*, AWRC Conference Series, AGPS, pp. 260-277.

LAKEY, R.C. 1983. Saline intrusion and channel dredging in the Western Port Groundwater Basin, Victoria. In *Collected Case Studies in Engineering Geology, Hydrogeology and Environmental Geology* (eds. M.J. Knight, E. Minty and R.B. Smith), Special Publication Geological Society Australia, no. 11, pp. 209-228.

LAKEY, R.C. & TICKELL, S.J. 1980. *Western Port 1:100 000 Sheet Hydrogeological Map.* Geological Survey Victoria.

LAKEY, R.C. & TICKELL, S.J. 1981. Explanatory notes on the Western Port Groundwater Basin 1:100 000 Hydrogeological Map. *Geological Survey Victoria Report* No. 69.

LEGGETT, J. 1997. Bass Valley Catchment Management Plan. Bass Coast Shire Council. 39p.

LEONARD, J.G. 1979. Preliminary assessment of the groundwater resources in the Port Phillip Region, *Geological Survey Victoria Report* no. 66.

LEONARD, J.G. 1992. An overview of Victoria's groundwater resources. *Background Report* S3 Short Term Planning Guidelines. Drought Management Plan for Victoria's Water Resources. Department of Water Resources, Victoria. Melbourne. 39p.

LEONARD, J.G. 1992. Management of Groundwater Systems in the Port Phillip Region of Victoria, Department of Water Resources Victoria.

LEONARD, J.G. 2003. Groundwater. In: Birch, W.D. ed. *Geology of Victoria*, pp 519-531. *Geological Society of Australia Special Publication* 23. Geological Society of Australia (Victoria Division).

PILLAI, M. 2002. Identification and assessment of salinity risk in the growth corridor of Cardinia Shire. *Centre for Land Protection Research Report No.8,* Department of Primary industries, Frankston.

PILLAI, M. & HEISLERS, D. 1999. 1999 Groundwater monitoring summary for the Rockbank – Balliang Area. *Centre for Land Protection Research brochure*. Department of Natural Resources and Environment, Bendigo.

PILLAI, M. & HEISLERS, D. 1999. 1999 Groundwater monitoring summary for the Upper Maribyrnong Area. *Centre for Land Protection Research brochure*. Department of Natural Resources and Environment, Bendigo.

PORT PHILLIP REGIONAL CATCHMENT AND LAND PROTECTION BOARD 1999. Dandenong Catchment Action Program. May 1999. 58p.

PORT PHILLIP REGIONAL CATCHMENT AND LAND PROTECTION BOARD 1999. Maribyrnong Catchment Action Program. May 1999. 73p.

PORT PHILLIP REGIONAL CATCHMENT AND LAND PROTECTION BOARD 1999. Werribee Catchment Action Program. May 1999. 73p.

PORT PHILLIP REGIONAL CATCHMENT AND LAND PROTECTION BOARD 1999. Westernport Catchment Action Program. May 1999. 73p.

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

SCOTT, K. 1992. Salinity discharge mapping for the eastern section of the Corangamite Salinity Region. Department of Conservation and Natural Resources, Geelong Region. 17p.

SHUGG, A., 1975. Progress report on the hydrogeology of the Tullamarine liquid waste disposal site. *Geological Survey Victoria Unpublished Report* 1975/23.

SHUGG, A. & HARRIS, I.F. 1975. Pumping test analysis Parker Road test site, parish of Wandin Yallock. Wandin Yallock 27 and 28. *Geological Survey Victoria Unpublished Report* 1975/90.

SKM, 2003. Cardinia Shire salinity project: Extent and severity of salinity in the Cardinia Shire Council. Sinclair Knight Merz Pty Ltd, 41p.

THOMAS, A. 1994. Salinity in the Yarra Catchment. *YarraCare Land Management Series, Discussion Paper* No.1. 19p.

THOMAS A. & BLUML M. 1992. Phillip Island Draft Salinity Management Plan. Phillip Island Community Salinity Consultative Group and Department of Conservation and Natural Resources, October 1992, 52p.

THOMPSON, B.R. 1974. Geology and hydrogeology of Westernport Basin, *Geological Survey of Victoria Report* 1974/3.

WALKER, G. & MOLLICA, F. 1990 Review of groundwater resources in the South East Region. *Water Resources Management Report Series*, Report 54. Department of Water Resources

YARRACARE 1999. Yarra Catchment Action Plan 1999. Department of Natural Resources and Environment, Box Hill. 120p.

Digital data sources:

Victorian Government Corporate Geospatial Data Library and Primary Industries Research Victoria, Bendigo.

- Mean annual rainfall (Bureau of Meteorology, 500 metre grid ESOCLIM data)
- Land Systems of Victoria (1:250,000 scale)
- Salinity (lines and polygons, various scales)
- Digital Elevation (Derived from 1:25,000 topographic map contours)
- Geology (1:250,000 scale)

Appendix 1

List of attendees at the Groundwater Flow Systems Workshop

Name	Affiliation
Vivian Amenta	DPI Frankston
Graeme Anderson	DSE Geelong
Shane Annett	DSE
Kirsten Barker	DPI
Darrell Brewin	Darrel Brewin & Associates Pty Ltd (workshop facilitator
David Buntine	PPWPCMA
Don Cherry	DPI (PIRVic Bendigo)
Peter Dahlhaus	Dahlhaus Environmental Geology Pty Ltd
Anne Davies	Phillip Island Landcare
Bob Davies	Phillip Island Landcare
Phil Dyson	Phil Dyson & Associates Pty Ltd (workshop facilitator)
Ray Evans	Salient Solutions Pty Ltd (workshop facilitator)
Sue Harris	Cardinia Shire
David Heislers	DPI (PIRVic Bendigo)
Greg Hoxley	Sinclair Knight Merz Pty Ltd
John Leonard	John Leonard Consulting Services Pty Ltd
Mick Lumb	PPWP CMA (Chairman)
Camille McGregor	Sinclair Knight Merz Pty Ltd
Tim O’Donnell	WACMAC
Mayavan Pillai	DPI (PIRVic Frankston)
Bronwyn South	PPWP CMA
Julie Weatherhead	Peppermint Ridge Farm
Julie White	DPI (workshop organiser)