Indicative Assessment of Climate Change Vulnerability for Wetlands in Victoria

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Introduction

The aim of this project was to undertake an assessment of the climate change vulnerability of Victoria's wetlands with a particular emphasis on understanding the likely changes in hydrological regimes and the regional distribution of these changes across Victoria.

The range of impacts that climate change may have on wetlands is wide and varied. Climate change is predicted to alter patterns of rainfall, river flow, groundwater level and sea level and also result in changes to other variables such as temperature and evaporation. These are all important drivers of wetland structure and function. However, the overarching driver is via changes in wetland hydrology, particularly the frequency and duration of inundation events. Changes in frequency and duration of the wet phase are predicted to result in a shift in vegetation community composition towards species tolerant of drier conditions and may also result in the loss of biodiversity, particularly if permanent wetlands dry out more frequently.

For this project we identified relevant climate change scenarios for assessment and assessed the impacts of these scenarios across Victoria to identify broad regional impacts. We compiled a database of wetlands across Victoria and assigned a primary water source and frequency of inundation to each wetland based on location in the landscape and the current Corrick and Norman wetland classification. We developed approaches to identifying the effects of climate change on the key hydrological drivers of wetland structure and function (namely river flow, rainfall, groundwater and sea level) and assessed the vulnerability of wetland to these changes at a regional scale. We also indentify knowledge gaps and recommend broad management actions aimed at helping to mitigate and adapt to climate change.

Climate change scenarios

Climate change scenarios, consistent with those used by the Department of Sustainability and Environment (DSE) for Sustainable Water Strategy planning, were adopted to represent the range of plausible climate change impacts:

a dry scenario based on current system operation with inflow reductions based on average changes in stream flows from 1997-2007 (i.e. step climate change model run F861). This is equivalent to Scenario D (continuation of recent inflows) used in the Victorian Sustainable Water Strategies; and

a wet scenario based on current system operation with inflow reductions based on CSIRO medium climate change predictions using CSIRO 2005 estimates to 2055 and baseline 1890 – 2010 (model run S861). This scenario is equivalent to Scenario B (medium scenario) used in Victorian Sustainable Water Strategies.

For sea level rise the A1FI coastal scenario – 0.8 m sea level rise by 2100 from the Victorian Future Coasts Program was adopted.

Regionalisation

Climate change is predicted to affect regions of Victoria in various ways. Existing climate change information for Victoria was reviewed and discussions were had with climate change specialists to determine an applicable climate change regionalisation for the State which could then be used to assess the vulnerability of wetlands under future climate scenarios on a regional basis.

The review of climate change information and consultation with climate change specialists led to the development of five climate change regions for Victoria.

Climate regions and associated river basins

Climate region	Associated river basins
North west	Campaspe, Loddon, Avoca, Mallee, Wimmera-Avon, Millicent Coast
North east	Goulburn, Broken, Ovens, Kiewa, Mitta Mitta, Upper Murray
South west	Glenelg, Portland Coast, Hopkins, Barwon, Lake Corangamite, Moorabool, Werribee, Maribyrnong
South east	Yarra, Western Port, Latrobe, South Gippsland, Thompson, Avon, Mitchell, Tambo, Otway
Far east	Snowy, Far East Gippsland

Under climate change the west of the State is likely to become drier than the east. In the far east, climate change is unlikely to result in significant drying. There is also an obvious divide in expected climate change impacts in northern and southern Victoria with the north likely to become drier than the south of the State.

The East Gippsland and Snowy basins were separated out as a region because they are likely to be more subject to the influence of east coast low pressure systems. The Otway basin has been grouped with the South east climate change region as changes in this basin are more closely aligned with this region rather than other south west regions due to less significant changes in rainfall.

Wetland water source and inundation classification

Wetlands are fed by various sources of water (river fed, groundwater, rainfall, marine derived) and many have more than one water source. The reliance upon each water source can change on a seasonal and yearly basis, depending on water availability and changes in management. For example, a floodplain wetland may be reliant on groundwater to sustain permanent moisture during dry periods but the characteristic structure and function of the wetland requires frequent surface water input as the main driver of the water regime.

While acknowledging that most wetlands have more than one water source, water source of wetlands has been determined for only a small number of Victorian wetlands through various regional inventory projects and there is limited data on water source at a State scale. Moreover, the relative dominance of different water sources is likely to vary, even at small spatial scales related to local factors such as geomorphology and geology, depth to water table etc. Hence, for simplicity we have assumed that wetlands have a primary water source which is the main driver of structure and function.

We undertook spatial analyses to assign one of the following primary water sources to each wetland:

- **River fed** – wetlands located on or immediately adjacent to rivers and channels. Included all wetlands located on alluvium or floodplain geomorphic units (GMUs) (except alpine wetlands). In some areas this may have overestimated the number of river fed wetlands where alluvium or floodplain GMUs were representative of paleo-systems, not contemporary floodplain systems.
- **Groundwater fed** – wetlands previously indentified on the State GDE wetlands layer as either permanent, semi-permanent saline or permanent freshwater wetlands. Where the GDE layer identified freshwater wetlands located on floodplain or alluvium GMUs then primary water source was assigned as river fed. However, it is likely that some of these wetlands receive water from multiple sources. The number of groundwater fed wetlands may have been overestimated in some areas where detailed analysis has shown that many should be more correctly classified as rainfall fed (e.g. the Wimmera region).
- **Rainfall fed** – wetlands that were not identified as groundwater or river fed and receive the bulk of their water from direct rainfall or runoff from small local catchments, including small intermittent inflowing streams and drainage lines. However, it is acknowledged that all wetlands receive rainfall and rainfall may indeed sustain wetlands during dry periods that might otherwise be river or groundwater fed. The analysis is aimed at an assessment of climate change vulnerability at a regional scale; while rainfall may sustain floodplain wetlands, they are still vulnerable to changes in river flows associated with climate change.

- **Coastal** – wetlands adjacent the coast (within 5 km) classified as saline or mapped with coastal Ecological Vegetation Classes (EVCs) dependent on or tolerant of saline conditions (i.e. estuarine reedbed, mangroves, coastal salt marsh).
- **Alpine** – wetlands located in alpine areas classified as alpine bogs or wet heathlands within sub-alpine and montane EVC groups.

We adopted a change in frequency of inundation as the indictor of wetland vulnerability. Using the Corrick and Norman wetland classification system and dominant vegetation type, three categories of inundation frequency were assigned.

- **Permanent**. Permanent wetlands in Victoria are already identified in the Corrick and Norman classification system and are systems that hold permanent water, although they still may dry out infrequently during prolonged drought.
- **Seasonal.** Seasonal wetlands were considered those that wet and dry every 1 to 2 years in response to seasonal rainfall, river flow and local groundwater variation. These correspond to Corrick and Norman sub-categories of herbs, sedges, rush, reed and red gum dominated wetlands.
- **Intermittent**. Intermittent wetlands were considered those that receive inundation every 3 to5 years (or less frequently i.e., including episodic and ephemeral wetlands), typically in response to larger flood events. These corresponding to the Corrick and Norman sub-categories of shrub, lignum, black box and cane-grass dominated wetlands.

For coastal wetlands, frequency of inundation was based on dominant vegetation type, which is governed by elevation relative to tidal ranges. Four categories were adopted.

- **Permanent**. Permanently inundated lagoons and coastal lakes located below the low tide level.
- **Tidal**. Located between the low and mean high tide marks. Wets and dries twice per day on tidal cycles.
- **Intermittent**. Located above the mean high tide level but is occasionally inundated by spring tides and storm surges
- **Episodic**. Located above the average high tide elevation and is rarely inundated by spring tides and storm surges

Approach to assessing wetland vulnerability

The assessment of wetland vulnerability was based on a change in the frequency of inundation from the primary water source. Predictions for river flow and rainfall under various climate change scenarios are available. Monthly river flow in many of Victoria's rivers has been modelled as part of the development of Sustainable Water Strategies for a number of climate change scenarios. Annual rainfall change has also been modelled. There is less information available on predicted changes in groundwater levels or rates of fluctuation. Sea level rise predictions were used to consider vulnerability of coastal wetlands, which were defined based on presence of saline tolerant/dependent vegetation.

For river fed wetlands, we assumed that under historical climate conditions flows that occur on average once every one to two years would inundate permanent and seasonal wetlands, while flows that occurred less frequently (e.g., once every three to five or more years) would inundate intermittent wetlands. Under climate change, the frequency of these flows is predicted to decrease. Where modelled data was available, we determined the magnitude of flows for a range of average recurrence intervals (ARI) under historical climate conditions and then determined how frequently those flow magnitudes are predicted to occur under climate change scenarios. We also calculated the average increase in the interval between these flow magnitudes and assumed that the changes in frequency of flows and interval between flow events would provide an indication of the change in frequency of inundation for floodplain wetlands that are reliant on river flow as their primary water source.

For rainfall fed wetlands we assumed that the median winter rainfall under historical climate conditions would be sufficient to inundate seasonal wetlands from direct rainfall and local catchment runoff. We then calculated the change in frequency of the historical median winter rainfall under each climate change scenario and related this to the likely inundation frequency of rainfall fed wetlands.

There are currently no regional predictions for how groundwater levels may change as a result of climate change. Hence, we have developed an approach for assessing potential impacts at a regional level based on historical correlations between rainfall and groundwater levels. For groundwater fed wetlands we assumed that if a decline in historical rainfall was correlated with a decline in groundwater level then groundwater fed wetlands would be vulnerable to climate change induced decline in rainfall.

For coastal wetlands vulnerability to change was based on sea level rise, although changes in freshwater inflow, groundwater and evaporation may also influence coastal wetlands.

Due to the nature of available data, the uncertainty of climate change predictions and the complexity of responses there are a number of assumptions that have been made in undertaking this project. These are detailed in the report.

State summary of wetland vulnerability

As a result of climate change there is predicted to be a reduction in rainfall across Victoria with the highest reductions being in the north and west of the state and the lowest reductions in the far east. This translates to a large reduction in stream flow, again with the north of the state most affected and the far east least affected. The reduction in rainfall and river flow translates to a large reduction in the frequency of stream flow events of the magnitude required to inundate river fed wetlands. Wetlands in the north and west of the state are likely to be most affected.

Predictions for impacts of climate change on groundwater levels are less well understood, although analysis suggests that for large, regional scale groundwater systems the response of groundwater levels to reduced recharge (reduced rainfall) is likely to take a long time to manifest. However, small scale, local groundwater systems are likely to respond much more rapidly to declining rainfall and reduced recharge. Hence, in local systems groundwater levels are likely to trend downwards much more rapidly in response to reduced rainfall. Wetlands that rely predominantly on groundwater from local groundwater flow systems are likely to be more immediately impacted by climate changed induced reductions in rainfall compared to wetlands that are associated with regional flow systems.

In coastal regions sea level will be the primary driver of wetland change; storm surges/storm tides will have an additional impact in some areas. The most vulnerable wetlands are those in intertidal zones where sea level rise will result in more permanent inundation, and those located above the intertidal zone in areas of low topography that may experience an increase in inundation frequency from sea level intrusion. Where there is an opportunity for coastal wetlands to migrate inland as sea level rises then there will be a change in distribution of wetlands but the diversity of wetlands types should still be maintained at a landscape scale. However, if landward migration is constrained by topography or linear infrastructure like sea walls and levees, then there will be a significant decline in the area of coastal wetlands.

Wetlands most vulnerable to climate change will be those:

- rainfall fed wetlands located in regions where reductions in rainfall are highest;
- river fed wetlands located on floodplains of rivers that will experience a large decrease in the frequency of high flow events;
- groundwater fed wetlands associated with local groundwater flow systems;
- alpine wetlands with high topographic elevation; and
- coastal wetlands located within and just above the intertidal zone and areas of low topography adjacent to embayments and estuaries and where landward migration is restricted due to topography or linear barriers.

For all inland wetlands, the primary impact of climate change, regardless of source water will be a reduction in the frequency and duration of inundation events and an increase in the duration of dry periods. The specific impacts on individual wetlands will depend on local characteristics. However, permanent wetlands will experience a more variable water regime with a shift towards a more seasonal wet and dry inundation pattern and may experience an increase in the number and /or duration of dry phases. Seasonal wetlands will experience a more intermittent wet phase and a longer duration dry phase. This may result in a shift in vegetation community structure away from flood dependent (aquatic and semi-aquatic) species to more flood tolerant species. Intermittent wetlands may experience a longer dry phase, although they are already adapted to a mostly dry regime, so from a biological perspective are likely to remain relatively unchanged. In summary, there will likely be a decrease in the number and area of permanent and seasonal wetlands and an increase in the number and area of intermittent wetlands.

At a regional scale, the regions were wetlands are most vulnerable are those where climate change will have the greatest impact on the frequency and duration of inundation events.

Summary of wetland vulnerability by wetland type across regions (indicative vulnerability green-low, yellow-moderate, red-high, black-not applicable).

Wetland type	Primary water source	Area (ha)	Num-ber	% area of state's wetlands				
				North west	South West	North east	South east & Otways coast	Far East
Permanent	River	68752	1379	65.8%	14.5%	17.4%	2.2%	<1%
	Rainfall	15289	1486	31.2%	64.9%	1.5%	2.4%	<1%
	Groundwater	56938	413	19.2%	77.8%	<1%	2.4%	<1%
	Alpine	5378	1218			94.8%	3.8%	1.4%
Seasonal	River	117400	5935	39.6%	8.6%	48.4%	2.4%	1.1%
	Rainfall	38827	5710	31.6%	56.8%	2.8%	8.8%	<1%
	Groundwater	65031	2655	73.5%	22.0%	1.2%	2.9%	<1%
	Alpine	929	291			11.9%	87.6%	<1%
Intermittent / episodic	River	19922	401	82.8%	5.9%	9.7%	1.5%	<1%
	Rainfall	4185	96	93.5%	6.4%	<1%	<1%	<1%
	Groundwater	4645	60	94.0%	5.7%	<1%	<1%	<1%
	Alpine	182	31			100.0%	0.0%	0.0%
Coastal (saline)	Permanent lagoon/lake	36659	109		4.0%		81.2%	14.8%
	Inter tidal	10342	147		0.3%		98.2%	1.2%
	Intermittent / episodic - above mean high tide	23152	466		23.0%		73.3%	3.5%
Unknown		15899	78	0.6%	10.3%	16.4%	55.4%	17.2%
Total		483530	20475					

River fed wetlands in the north west region are most vulnerable, followed by river fed wetlands in the south west and north east (particularly those towards the western part of the region in the Goulburn River catchment). Rainfall fed wetlands in the north east and south east are at moderate vulnerability, particularly under stepped climate change. Groundwater fed wetlands most vulnerable are those associated with local groundwater systems. All regions support these types of wetlands, although lack of data on the specific numbers of wetlands associated with local or regional groundwater flow systems makes an assessment of specific vulnerability difficult. Hence, an overall medium level of vulnerability has been assigned. On a state basis, most groundwater fed wetlands are located in the south west and north west regions, so these areas are likely to be particularly impacted. Alpine wetlands in the north east and south east are likely to be of medium to high vulnerability – they rely partly on local rainfall and any reduction in rainfall will impact on hydrological regimes. Coastal wetlands in the south west, south east and far east are all vulnerable to sea level rise and increased storm surge intensity and frequency.

Areas most vulnerable due to a lack of opportunity for landward redistribution are around Port Phillip and Western Port Bays (constrained by infrastructure) and along the Otway and far east coasts (constrained by topography).

Management actions and recommendations

A range of management actions are available depending on the primary water source and opportunities for securing and delivering alternative sources of water. For river fed wetlands actions should be targeted at:

- Establishing water management plans and environmental water entitlements for high value and strategic wetlands. High value wetlands are those that support important biological, social and economic values. In most regions these wetlands have already been identified and for some of them, water regime management plans and environmental entitlements are already established. Further work is required to indentify a network of *strategic* wetlands that collectively provide a range of wetlands types across the landscape that enable conservation of wetland types and associated biodiversity at a regional scale. Effort is then needed to establish water management plans, water delivery options/infrastructure and environmental entitlements to deliver water according to the desired regime.
- Removal or modification of barriers (e.g. regulators, levees, block banks, lowering commence to fill levels etc). These actions require case by case investigations and water management option development.

For rainfall fed wetlands actions should be targeted at:

- Improved management of farm dams through limits on the size of farm dams and the installation of low flow bypass structures to limit the amount of water captured in farm dams and diverted away from wetlands.
- Prevention, and where possible, reversal of local drainage schemes, especially where wetlands have been historically drained or local catchment runoff has been artificially diverted around and away from natural wetlands.

For groundwater fed wetlands actions should be targeted at:

- limiting the cumulative effects of groundwater pumping on wetlands and land use change that may reduce recharge opportunities.

For alpine wetlands actions to manipulate the hydrological regime are limited due to their location in the landscape and reliance on a combination of rainfall and groundwater. However, complimentary actions to prevent degradation of alpine wetlands are warranted. Actions to prevent disturbance to the peat structure (e.g. through fire, physical damage etc), which can accelerate drying, are necessary.

Of all wetland types, coastal wetlands (whose primary water source is the sea) have the greatest opportunity to adapt to climate change. Coastal wetlands will be lost through inundation, but where opportunities for landward migration existing they will re-establish at a new elevation relative to the new sea level. Management actions are needed to help facilitate this redistribution, and include:

- Land use assessments to identify specific areas where coastal wetlands can re-establish and planning scheme amendments to protect these areas so that new wetlands can establish over time; and
- Assessments of infrastructure constraints and consideration/incorporation of actions to assist wetland migration when designing and constructing new or upgraded existing coastal infrastructure. This is particularly relevant in the context of coastal planning and asset protection activities being undertaken in preparation of climate change impacts.

For all wetlands, management of other degrading factors such as stock access, grazing and cropping activities, weed infestation etc are required to provide the best opportunity for wetlands to adapt to climate change.

A number of knowledge gaps / uncertainties exist in the analysis and recommendations are made for dealing with these knowledge gaps and for further research.

The analysis of climate change impacts on river flow was undertaken using modelled data of monthly flow. Events that inundate wetlands typically occur at the daily rather than monthly scale. Hence monthly data can mask higher flow events that occurred for just a few days but resulted in wetland inundation. However, the available modelling of climate change impacts on river flows has been undertaken at a monthly time step, not a daily time step, so data is not available to enable a daily time step analysis.

Recommendation: If daily modelling of climate change impacts on flows becomes available then the analysis could be repeated and updated to reflect the more accurate data.

Analysis of change impacts on flow regime were only able to be completed for selected river system where climate change modelling has already been undertaken. These rivers were typically the larger, regulated rivers where water resource demand modelling has been undertaken to inform the development of sustainable water strategies. Hence, the analysis is biased towards these systems and may not adequately represent the impacts that climate change might have on flow in smaller and/or unregulated systems.

Recommendation: If modelling of climate change impacts on flows in these smaller, unregulated rivers is undertaken in the future then the analysis of impacts on wetlands could be repeated.

Flow analysis was undertaken for selected river systems and was based on an assumption that high flows would inundate wetlands. The analysis was not based on an assessment of specific wetland commence to flow thresholds.

Recommendation: If a more detailed analysis is required at the site level then it would be possible to repeat the analysis but instead of using an Average Recurrence Interval flow magnitude as the trigger for wetland inundation the analysis would be undertaken for specific flow thresholds known to inundate target wetlands. Catchment Management Authorities interested in the impacts of climate change on specific wetlands could use this approach, although the uncertainty around the use of monthly flow remains.

Rainfall analysis assumed that most rainfall fed wetlands in the landscape would be inundated if the area received the median cumulative winter rainfall. This assumption has not been tested. Furthermore, impacts of climate change on rainfall were based on estimates of the annual reduction in rainfall scaled down to monthly. The scaling did not include seasonal factoring and it is probable that climate change will have a seasonal effect on rainfall reduction.

Recommendation: Future analysis needs to test the assumption around the magnitude of rainfall required to fill rainfed wetlands and also incorporate seasonal factoring in rainfall predictions. Testing of this assumption could be undertaken at the site scale for selected individual wetlands where information is available on the historical wetting regime that can be correlated with rainfall at a nearby gauging location.

Impacts of climate change on groundwater levels are not well understood. This study assumed that local groundwater systems that rapidly respond to decadal rainfall patterns will also respond to climate change whereas regional groundwater system that do not respond to decadal patterns in rainfall are less likely to affected by climate change. However, there is limited empirical information to support this assumption, analysis was based on examination of existing groundwater level data at a few sites and applied across a region. Furthermore, the mapping of local and regional groundwater systems is often at a scale that doesn't allow one to accurate assignment of a wetland to a particular groundwater system.

Recommendation: Research opportunities exist to further understand the response of groundwater to climate change, including the confounding impacts of recharge and evapotranspiration. In addition, improved mapping of groundwater systems and development of a more accurate GDE layer would greatly improve the analysis, as would more accurate correlation between specific wetlands and particular groundwater systems. Site specific investigations are required to gain a better understanding of the groundwater dependency.

Impacts on coastal wetlands are described in general. Coastal wetlands whose primary water source is marine-derived have the capacity to respond to climate change by landward migration and redistribution. However, opportunities for landward migration are limited by topography and the presence of man-made barriers. For a broad regional project we have not identified specific locations where landward migration is or is not possible as an adaptation response.

Recommendation: Site specific investigations and mapping are required at the local scale to determine the specific impacts of sea level rise on coastal wetlands and to indentify local barriers to migration and hence specific adaptation potential.

We have assumed the wetlands have a single primary water source. However, it is most probable that wetlands receive water from several sources and that each source may play a defined role in wetland function. For example, groundwater may sustain the wet phase of a floodplain wetland but variability in water level is provided by regular overbank river inundation. For the regional assessment we have only assessed primary water source impacts.

Recommendation: Site specific investigations could be undertaken at selected representative wetlands in each CMA area to better understand the interrelationships and interdependency between various water sources. Factors to consider are the roles each water source plays in wetland structure and function, the timing of such interdependency and the relative threats associated with climate change impact where a wetland is dependent on several water sources.

We have assumed that wetland plant and animal community composition and ecosystem structure and function is driven in large part by the existing water regime. Following on from this, a reduction in the frequency of wetland inundation (as indicated by the completed analysis) is predicted to lead to a change in wetland structure and function. However, there is great uncertainty around the ability of many wetland species to survive an increased dry phase interval. There is also uncertainty around other threats and the interactions between these and changes in hydrology associated with climate change, for example acid sulfate soils, invasion by pest species and changes in the distribution of C3 and C4 plants and changes in evapotranspiration amongst other things.

Recommendation: An opportunity currently exists to undertake monitoring and research investigations around the resistance and resilience of wetland species and wetland function to prolonged dry phases. Many wetlands have been inundated during the second half of 2010 for the first time in 10 or 15 years. Surveys of these systems (e.g. Avoca marshes, rainfall wetlands on the Millicent Coast basin etc) should be considered to determine how they respond to this inundation and to benchmark community composition and where possible link this back to species present during previous inundation events. This information would be extremely useful in helping to understand how long wetlands can experience a dry phase before structure and function change, and also provide information on other threats and interactions.

Selected wetlands could be established as Sentinel Sites that can be used in long term monitoring of the impacts of climate change. Sentinel Sites should comprise of a range of wetland types and water sources in coastal areas and both regulated and unregulated catchments across each climate change region or CMA. They could act as early warning sites of impending change and also be used to monitor trends in condition as climate change impacts become established.

This study represents a broad regional assessment of climate change impacts on water regimes of wetlands using existing information on predictions for changes in river flow, rainfall and sea level rise. The outcomes add to existing climate vulnerability knowledge by generating more detailed predictions about the vulnerability of wetlands to climate change. These results will be used to support the development of policy and strategic planning for wetlands.

1 Introduction

1.1 Project objectives

Climate change is predicted to alter patterns of rainfall, river flow, groundwater level and sea level. These are all important drivers of wetland structure and function. Hence, wetlands are likely to be particularly vulnerable to climate change. The specific impacts on individual wetlands can only be determined based on site specific investigations, however it is desirable to understand the vulnerability of different wetlands types at a broader regional scale. The aim of this project is to undertake an assessment of the climate change vulnerability of Victoria's wetlands with a particular emphasis on understanding the likely changes in hydrological regimes and the regional distribution of these changes across Victoria.

1.2 Project outcomes

This project will add to existing climate vulnerability knowledge by generating more detailed predictions about the vulnerability of wetlands to climate change. These results will be used to support the development of policy and strategic planning for wetlands by the Department of Sustainability and Environment (DSE) in Victoria. The information will also inform regional strategic planning for wetland management and help in prioritising wetlands for management actions to protect regional biodiversity and conservation values. The project also identifies knowledge/data gaps and monitoring and research needs.

1.3 Project rationale

Victoria's water resources are likely to become increasingly vulnerable to climate change, due to projected drying trends over much of the State. At the same time, demand for water may grow as a result of increasing population, warmer temperatures and higher evaporation rates. Water quality may be affected by changes in water temperature, carbon dioxide concentration, transportation of water sediment and chemicals, and the volume of water flow. Decreases in stream flow, impacts on coastal groundwater and intertidal habitats, and increased salinity will be critical issues for the management of Victoria's water resources (Victorian Government 2010).

Climate change will impact on Victoria's inland wetlands through reduction in rainfall, changes in the frequency of river flows that inundate wetlands and changes in groundwater levels related to reduction in rainfall. Wetlands in coastal areas will be subjected to sea-level rise, storm surges, increased temperatures and coastal inundation and erosion. Although the exact nature of impacts are difficult to predict, many natural systems, including wetlands, are likely to have difficulty adapting to climate change, and may become increasingly vulnerable. Wetlands will undergo changes in hydrological and salinity regimes under climate change as well as be exposed to extreme weather events. A future hotter and drier climate may reduce many wetlands in size, convert some wetlands to dry land, or shift one wetland type to another. Climate change and rising sea levels will likely lead to a significant loss and degradation of wetlands and associated biodiversity in Victoria (Jin *et al*. 2009).

DSE has been investing in climate change vulnerability projects in order to facilitate an adaptive approach to ecosystem management under climate change and inform Victorian water resource policy. Prioritisation of wetlands based on future conditions helps guide investment and predict longer term viability.

Projects have included climate change and salinity projects such as 'Wetlands, Biodiversity and Salt' undertaken by ARI, the recent 'Climate Change Impacts on Wetlands in Victoria' also undertaken by ARI (Jin *et al.* 2009); and the current 'Future Coasts Program' being run in partnership with the Department of Planning and Community Development. These projects, and others like them, have provided DSE and the greater Victorian community with information about the impacts of climate change.

1.4 Victoria's wetlands

Wetlands are areas of land where water covers the soil – all year or just at certain times of the year. They include (http://www.environment.gov.au/water/topics/wetlands/):

- swamps and marshes ;
- billabongs, lakes and lagoons;
- saltmarshes, mudflats and mangroves; and
- bogs, fens, and peatlands.

Water for wetlands is derived from four main sources, direct rainfall and localised catchment runoff, groundwater, overflow from rivers and sea water. Most wetlands receive water from a combination of sources, although one source is often the dominant driver of structure and function.

A wide range of wetlands exist in Victoria across all bioregions. The State wetlands inventory compiled includes over 20,000 wetland polygons (approximately 12,800 individual wetlands) with a total area of greater than 480,000 Ha. Wetland polygons associated with floodplains make up the largest number (~7700 or ~38%) of wetlands and also the greatest area (~206,600 Ha or ~42%). Most wetlands are located in the north and south west of the state.

Wetlands are an important ecosystem type. For example, they provide floodplain storage capacity that helps reduce the impacts of floods, coastal wetlands help buffer erosive forces, they can also act to absorb pollutants and improve water quality. Wetlands also provide habitat for a wide range of plants and animals, including many threatened species. In addition, wetlands provide important social and economic services.

In Victoria, many wetlands are protected in parks and reserves, although many more are located on private land and have been subjected to a range of impacts over many years. Impacts include, drainage, clearing of vegetation, grazing and cropping and weed infestation. For many wetlands, their hydrological regime has been significantly altered from natural, particularly for wetlands located in the heavily regulated catchments. In these areas some wetlands have become permanently inundated (e.g. some wetlands in the Kerang Lakes complex), while others have experienced a reduction in the frequency and/or duration of inundation and a change in the timing of inundation (e.g. the lower Goulburn floodplain and lower Latrobe River and Lake Wellington wetlands). The hydrological regime of wetlands is a critical characteristic that defines the plant and animal species and ecosystem functions that occur in each wetland, so changes in hydrological regime can have significant impacts on wetland structure and function.

Climate change poses a new threat to the hydrological regime of all wetlands across Victoria. The relative vulnerability of Victoria's wetlands depends on factors such as the magnitude of change in hydrological drivers (rainfall, river flow, groundwater level and sea level) and the interactions and interrelations with other climate change influenced variables such as temperature, evapotranspiration and frequency and intensity of extreme events.

1.5 Climate change

In general, Victoria's future climate is likely to be hotter and, for most of the state, drier (Jones and Durak 2005). Sea level will also rise. The north and east of the state are expected to experience greater temperature increases than the south and west. Temperature increases are likely to be greatest in spring and summer and least in winter. The greatest decreases in rainfall are likely to occur in winter and spring, while heavy rainfall intensity is most likely to increase in summer and autumn. The drying is likely to be greater in central and western regions. By 2030, catchments in the northeast and southeast may experience up to 30% less runoff, those in the northwest between 5% and 45%, and those in the southwest between 5% and 40% (Figure 1.1). By 2070, runoff into catchments in East Gippsland may change by between –50% and +20%, depending on changes in rainfall. The rest of the state can expect declines between 5% and 50% (Jin *et al* 2009). The changing climate will lead to decreases in precipitation, surface runoff and groundwater recharge and increases in evaporation and transpiration across much of Victoria, and drought will become more severe (DSE 2009c).

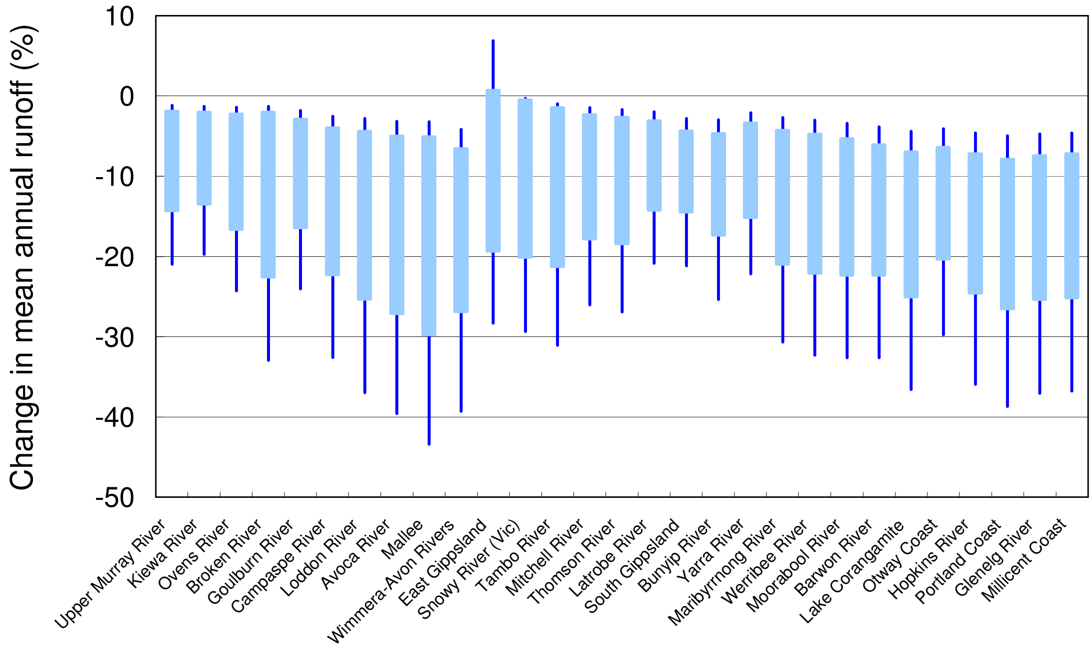


Figure 1.1 Range of possible change in runoff for 2030 across Victoria's river basins. The vertical lines measure the total range of change from ten climate models with a range of global warming of 0.54–1.24°C. The central boxes project the range of change at a 0.85°C (median) global warming. Note that the Mallee has no effective runoff (Source: Jones and Durak 2005).

1.6 Climate change impact pathways on wetlands

Impacts of climate change range from the direct effects of changes in climatic variables (e.g. temperature, precipitation and drought) to indirect effects through interactions with non-climatic drivers (e.g. land and water use, species interactions, and disturbances such as bushfire, salinisation, eutrophication and acidification). Responses of wetland ecosystems to changes in climate involve complex interactions of biotic and abiotic components and processes and their landscape context (Jin *et al.* 2009). The responses of wetlands to climate change are a result of a balance between changes in water regime, temperature, nutrient cycling, physiological acclimation and community reorganisation (Oechel *et al* 2000).

For inland wetlands, climate change is likely to in a reduction in the frequency and duration of wetland inundation events. A review by Nielsen and Brock (2009) of climate change impacts on wetlands predicts that wetlands will become drier and that animal and plant communities will shift from those reliant on frequent flooding to those tolerant of occasional flooding (Table 1.1).

Table 1.1 Predicted changes in wetlands (permanent and temporary) and their biotic communities in response to forecasts of change in climate change drivers reproduced with permission Nielsen and Brock 2009)

Driver	Changes–permanent wetlands		Changes–temporary wetlands	
	Wetland changes	Biotic changes	Wetland changes	Biotic changes
Decreased rainfall	↓ Connectivity ↓ Wetland flushing ↑ Salinity ↑ Drying means ↓ wetlands in landscape	↓ Biota before salinity exceeds 1 g L^{-1} ↑ Distance for dispersal & recolonisation ↓ Habitat structure	↓ Inundation periods ↑ Dry periods ↓ Flushing of salts leads to ↑ salinity	↓ Time for biota to reproduce ↑ Seedbank depletion with ↑ drying time ↓ Habitat structure
Increased temperature	↑ Evaporation leads to ↓ water levels	↓ Time for biota to reproduce ↓ Habitat structure	↓ Inundation periods ↑ Concentration of salt	↓ Time for biota to reproduce ↑ Seedbank depletion with ↑ drying time ↓ Habitat structure ↓ Biota before salinity exceeds 1 g L^{-1}
Extreme events (short intense rainfall events)	↓ Connectivity ↓ Inundation times ↑ Drying means ↓ Wetlands in landscape	↓ Biota as permanent wetlands ↓ ↑ Time and distance for dispersal & recolonisation ↓ Habitat structure	↑ Dry periods	↑ Seedbank depletion with ↑ drying time ↓ Habitat structure
Salinity	↑ Salinity from ↓ flushing, evaporation & intrusion of saline groundwater	↓Biota before salinity exceeds 1 g L^{-1} ↓ Biotic diversity ↓ Habitat structure	↑ Salinity from reduced flushing and evaporation	↓ Biota before salinity exceeds 1 g L^{-1} ↓ Biotic diversity ↓ Habitat structure
Management intervention	Managed for permanent water supply as permanent water reserve	↓ Loss of variability ↓ Habitat diversity ↓ Biotic diversity	↑ Periods of dry ↓ Reliability as seasonal water ↑ In cropping	↓ Time for biota to reproduce ↑ Seedbank depletion with ↑ drying time ↓ Habitat diversity ↓ Seedbank depletion through mechanical disturbance

Seedbank refers to dormant eggs of zooplankton and seeds of plants; (↓) decrease or reduction or loss of and (↑) increase or gain

Coastal wetlands will be inundated by seawater longer and more often because of sea level rise and storm surge (Jin *et al* 2009). Also, reduced freshwater runoff will decrease freshwater input to coastal wetlands. Climate change is predicted to result in a 0.8 m rise in sea level. This rise in sea level will have varying impacts depending on topography of the coastline. In low relief areas, sea level rise is likely to result in the permanent inundation of wetlands that are currently tidal. These wetlands comprise mostly mangrove and estuarine reed bed wetlands. Wetlands that are currently intermittently inundated during spring tides and storm surges will become more frequently inundated. These wetlands are mostly coastal saltmarsh systems (Vanderzee, 1998). A change in the frequency of sea water inundation will have dramatic effects on wetland vegetation types (Bird 1993, Cahoon *et al.* 2006). Mangroves will advance into saltmarsh communities and where topography allows, saltmarsh may be able to migrate inland. However, in many areas topography and also man-made features, such as seawalls, roads, drains and agricultural land will prevent the landward migration of coastal wetlands (Boon *et al.* 2010). Permanent coastal wetlands will persist, although their distribution will change, as too will tidal systems like mangrove wetlands. However, intermittent and episodic coastal wetlands (e.g. saltmarsh and estuarine (*Melaleuca*) scrubs) will be at most risk because of barriers to migration associated with topography and land use and are likely to diminish significantly in area.

1.7 Scope of works

The range of impacts that climate change may have on wetlands is wide and varied, but the overarching driver is via changes in wetland hydrology, particularly the frequency and duration of inundation events. The impacts of climate change on rainfall and flow has been extensively modelled for a range of climate scenarios. The scope of this project focuses on the impacts that climate change is likely to have on the hydrology of wetlands.

This requires consideration of the range of wetland types under plausible climate change scenarios over the next 20-30 year period to make an assessment of the likely shifts in hydrological regimes. For coastal wetlands, it requires an estimate to future changes in wetland extent due to predicted sea level rise.

These assessments are made on a region scale, which takes account of regional variability of future climate predictions throughout Victoria using predominately spatial analyses. This assessment draws on a combination of existing data, scientific evidence and specialist opinion.

2. Methods

This section describes approaches for:

- identifying climate change scenarios adopted for the project;
- predicting regional variation in climate change impacts;
- classifying wetlands according to their primary water source; and,
- determining how the frequency of wetland inundation might change across regions under the various climate scenarios based on how primary water source is predicted to change.

2.1 Climate Change

2.1.1 Scenarios

Various climate change scenarios applied throughout Victoria in NRM planning were reviewed and assessed for their applicability to this project. Specialist advice was sought in the identification of appropriate climate change scenarios for the project with reference to current projects of high and current relevance: *Future Coasts* (e.g. McInnes *et al.* 2009) and *Sustainable Water Strategies* (e.g. DSE 2008, 2009b, 2010b).

Considerations in the selection of climate change scenarios for inland wetlands related to:

- the need for discrimination in the possible outcomes for wetlands given the level of uncertainty in how changes in climate translate to changes in wetland water regime; and
- the probable range in climate change outcomes.

The specific scenarios are described in more detail in the Results section (Section 3.1.1).

2.1.2 Regionalisation

Climate change is predicted to affect regions of Victoria in various ways. Existing climate change information for Victoria was reviewed and discussions were had with climate change specialists to determine an applicable climate change regionalisation for the State which could then be used to assess the vulnerability of wetlands under future climate scenarios on a regional basis. Regionalisation was based on consideration of the both the predicted climate change impacts and on existing management boundaries (i.e. Catchment Management Authority boundaries and river basins). This regionalisation attempts to capture dominant changes on a regional scale (see Section 3.1.1 for results).

2.1.3 Regional climate change data

Changes in climate and water availability at a regional scale have been investigated and modelled for the Sustainable Water Strategies (e.g. DSE 2008, 2009b, 2010b) and work undertaken by Jones and Durack (2005) for Victorian basins. We collated documented changes in the major inputs to wetland water balances (i.e. catchment runoff, river flows, rainfall, aquifer levels and sea level) at the regional scale where such modelling was available. We sought specialist advice on other inputs where investigation and modelling was not available for each of the regions under the two climate change scenarios. For example, while modelling has been generally been undertaken to predict average reduction in stream flows, the consequent reductions in the frequency of flooding for floodplain wetlands has not generally been investigated.

2.2 Wetlands

2.2.1 Primary water source

Wetlands are fed by various sources of water (river fed, groundwater, rainfall, marine derived) and many have more than one water source. The reliance upon each water source can change on a seasonal and yearly basis, depending on water availability and changes in management. For example, a floodplain wetland may be reliant on groundwater to sustain permanent moisture during dry periods but the characteristic structure and function of the wetland requires frequent surface water input as the main driver of the water regime.

While acknowledging that most wetlands have more than one water source, water source of wetlands has been determined for only a small number of Victorian wetlands through various regional inventory projects and there is limited data on water source at a State scale. Moreover, the relative dominance of different water sources is likely to vary, even at small spatial scales related to local factors such as geomorphology and geology, depth to water table etc. Hence, for simplicity we have assumed that wetlands have a primary water source which is the main driver of structure and function. However, it should be noted that the specific response of individual wetlands to a change in water source will vary according to the relative dominance of different sources. This can only be assessed at the site specific scale, which is beyond the scope of the current project.

In order to assign a primary water source at an indicative level to Victorian wetlands we first needed to develop an updated wetlands layer using the Victorian statewide wetlands geospatial inventory (Wetlands_1994) layer as a base but including other more recent regional wetland datasets generated by Catchment Management Authorities (CMAs). The specific data layers used to prepare an updated inventory of wetlands for the project are described below and attributes are provided in Appendix A.

- Wetlands_1994 is a statewide inventory of wetlands prepared primarily from air photo interpretation of wetland boundaries. Data was collated in the period from the late 1970s to 1994. The inventory includes both natural and artificial wetlands. Only natural wetlands were included for this project.
- Mallee wetlands – based on Wetlands_1994 layer but updated by Mallee CMA.
- Wimmera wetlands - based on Wetlands_1994 layer but updated by Wimmera CMA.
- North east wetlands - based on Wetlands_1994 layer but updated by North East CMA.
- West Gippsland wetlands - based on Wetlands_1994 layer but updated by West Gippsland CMA.
- Alpine bogs and wet heathlands – specific layer developed to capture alpine wetlands (from Lawrence, *et al.* 2009).
- The Ramsar site geospatial layer depicts the boundaries of wetlands of international importance (Ramsar sites) listed under the Ramsar Convention. It was prepared in 1995.

Additional datasets used in the project are described below.

- State GDE layer – The GDE wetland layer was developed primarily upon the outcome of reviewing literature on groundwater and surface water connection (Dressel *et al.* 2010). Where previous investigations had established groundwater connection to a wetland it was categorised as a GDE, if the wetland existed within a series of wetlands, for example the Cockajemmy Lakes, then the entire system was deemed to be a GDE. The temporal nature of groundwater connection was not evaluated, such that a wetland GDE may have permanent, seasonal or episodic groundwater interaction and may also have surface water and local rain water sources as well.
- Geomorphology of Victoria (DPI 2009) – This layer maps geomorphological units (GMUs) at a range of scales. We used the Tier 3 scale at 1:100k-500k to indentify floodplain and alluvium GMUs that would provide an indication that wetlands located on these GMUs had a high likelihood of being river fed. Although, at this scale alpine wetlands are associated with floodplain GMUs, they have been treated separately because a specific alpine wetlands layer is available and because of the unique interaction between various water sources that drive alpine wetland structure and function.

We undertook spatial analyses using these datasets to assign one of the following primary water sources to each wetland.

- River fed – wetlands located on or immediately adjacent to rivers and channels. These included all wetlands located on alluvium or floodplain geomorphic units (GMUs) (except alpine wetlands). In some areas this may have overestimated the number of river fed wetlands where alluvium or floodplain GMUs were representative of paleo-systems, not contemporary floodplain systems (e.g. particularly parts of the Wimmera region).
- Groundwater fed – wetlands previously indentified on the State GDE wetlands layer as either permanent, semi-permanent saline or permanent freshwater wetlands. Where the GDE layer identified freshwater wetlands located on floodplain or alluvium GMUs then primary water source was assigned as river fed. However, it is likely that some of these wetlands receive water from multiple sources. The number of groundwater fed wetlands may have been overestimated in some areas where detailed analysis has shown that many should be more correctly classified as rainfall fed (e.g. the Wimmera region).
- Rainfall fed – wetlands that were not identified as groundwater or river fed and receive the bulk of their water from direct rainfall or runoff from small local catchments, including small intermittent inflowing streams and drainage lines. However, it is acknowledged that all wetlands receive rainfall and rainfall may indeed sustain wetlands during dry periods that might otherwise be river or groundwater fed. The analysis is aimed at an assessment of climate change vulnerability at a regional scale. While rainfall may sustain floodplain wetlands, they are still vulnerable to changes in river flows associated with climate change.
- Coastal – wetlands adjacent the coast (within 5 km) classified as saline or mapped with coastal Ecological Vegetation Classes (EVCs) dependent on or tolerant of saline conditions (i.e. estuarine reedbed, mangroves, coastal salt marsh).

- Alpine – wetlands located in alpine areas classified as alpine bogs or wet heathlands within sub-alpine and montane EVC groups.

2.2.2 Wetland water regime and classification

Wetland water regime (source, quality, timing, duration, depth and frequency of inundation) are all critical drivers of wetland structure and function (Casanova and Brock 2000). A change in some aspect of a wetland's water regime, such as frequency of inundation, or a shift from one water source to another, for example if sea level rise extends estuarine conditions upstream, could alter critical wetland characteristics and hence wetland type.

Climate change has the potential to impact on several components of a wetland water regime, but the components most likely to be impacted are the frequency and duration of inundation (Nielsen and Brock 2009). A decrease in frequency of inundation may occur as a result of reduced rainfall leading to a reduction in surface runoff to rain fed wetlands, a reduction in the frequency of overbank flows that inundate river fed wetlands and a fall in groundwater levels below the bed level of groundwater fed wetlands. For coastal wetlands, climate change is likely to result in a sea level rise that will inundate some wetland types depending on elevation (Boon *et al*. 2010).

Based on the climate change information available, we have adopted a change in frequency of inundation as the indictor of wetland vulnerability.

The current wetland classification system in Victoria (based on Corrick and Norman (1980, 1982) (Table 2.1) provides some information on water regime characteristics of wetland categories.

Table 2.1 Victorian wetland classification (after Corrick and Norman 1980, 1982).

Category	Category name Depth (m)	Duration of Inundation	Sub-category number	Sub-category name
2	Freshwater Meadow < 0.3m	< 4 months / year	1	Herb-dominated
			2	Sedge-dominated
			3	Red Gum-dominated
			4	Lignum-dominated
			5	Black Box-dominated
			6	Cane Grass-dominated
3	Shallow Freshwater Marsh < 0.5 m	< 8 months / year	1	Herb-dominated
			2	Sedge-dominated
			3	Cane Grass-dominated
			4	Lignum-dominated
			5	Red Gum-dominated
			6	Black Box-dominated
			7	Dead Timber-dominated
			8	Rush
			9	Reed

Table 2.1 (continued).

Category	Category name Depth (m)	Duration of Inundation	Sub-category number	Sub-category name
4	Deep Freshwater Marsh < 2m	> 8 months / year - permanent	1	Shrub-dominated
			2	Reed-dominated
			3	Sedge-dominated
			4	Rush-dominated
			5	Open-dominated
			6	Cane Grass-dominated
			7	Lignum-dominated
			8	Red Gum-dominated
			9	Dead Timber-dominated
			10	Black Box-dominated
5	Permanent Open Freshwater	permanent	1	Shallow Open Water (<2)
			2	Deep Open Water (>2)
			3	Impoundment
			4	Red Gum-dominated
			5	Cane Grass-dominated
			6	Dead Timber-dominated
			7	Black Box-dominated
			8	Rush-dominated
			9	Reed-dominated
			10	Sedge-dominated
			11	Shrub-dominated
			12	Lignum-dominated
6	Semi-Permanent Saline Wetland < 2m	< 8 months / year	1	Salt Pan
			2	Salt Meadow
			3	Salt Flats
			4	Juncus-dominated
			5	Hypersaline-dominated
			6	Melaleuca-dominated
			7	Dead Timber-dominated
7	Permanent Saline Wetland	permanent	1	Shallow Open Water (<2)
			2	Deep Open Water (>2)
			3	Intertidal Flats
			4	Juncus-dominated

Within the current classification, wetland categories 2, 3, 4 and 6 are considered to be alternately wet and dry. That is they are inundated once a year or less frequently and dry out between wetting events. Wetland categories 5 and 7 are considered permanently wet, but may dry on rare occasions during very dry periods.

Wetlands that are alternatively wet and dry can be further classified based on the frequency and duration of inundation (Table 2.2). The frequency of the wetting event (duration of the dry period) typically determines the dominate vegetation types present (Casanova and Brock 2000, Barrett *et al*. 2010). For example, wetlands that are frequently wet are likely to support aquatic and semi-aquatic vegetation and some shrub and tree species (e.g. River Red Gum) that are dependent on flooding. Whereas wetlands inundated less frequently tend to support shrubby vegetation and grasses that are flood tolerant rather than flood dependent. Wetlands that are variably wet and dry exhibit the highest species diversity, whereas permanently wet or nearly always dry wetlands tend to be dominated by just a few species (Barrett *et al*. 2010).

Table 2.2 Simplified classification of temporary wetlands (adapted from Boulton and Brock 1999).

Wetland type	Predictability and duration of filling	Frequency	Duration	Seasonality
Ephemeral	Filled only after unpredictable rainfall and runoff. Surface water dries within a couple of days of filling and seldom supports macroscopic aquatic life	doesn't fill every year	< 1month	
Episodic	Dry most of the time, with rare and very irregular wet phases that may persist for months. Annual inflow is less than minimum annual loss in 9 years out of 10.	doesn't fill every year	>1 month and <12 months	variable
Intermittent	Alternately wet and dry, but less frequently and less regularly than seasonal wetlands. Surface water persists for months to years after filling.	doesn't fill every year	variable	fills in same season predominantly winter/spring
Seasonal	Alternately wet and dry every year, according to season. Usually fills in the wet part of the year and dries predictably every year during the dry season. Surface water persists for months, long enough to support macroscopic aquatic life. Biota adapted to desiccation.	annual	>1 month and <12 months	fills in same season predominantly winter/spring
Permanent	Predictably filled although water levels may vary across seasons and years. Annual inflow is greater than minimum annual loss in 9 years out of 10. May dry-out during droughts. Biota generally cannot tolerate desiccation.	constant or annual	never dries	fills all year or seasonally

For this project, an attempt was made to assign a level of frequency of inundation to the Corrick and Norman classification system based on dominant vegetation type, but the quality and extent of vegetation wetland mapping limited this to three categories: permanent, seasonal and intermittent. Permanent wetlands in Victoria are already identified in the Corrick and Norman classification system. Seasonal wetlands were considered those that wet and dry every 1 to 2 years. These were considered to correspond to Corrick and Norman sub-categories of herbs, sedges, rush, reed and red gum dominated wetlands. Intermittent wetlands were considered those that receive inundation every 3 to 5 years (or less frequently i.e., including episodic and ephemeral wetlands – Table 2.2), corresponding to the Corrick and Norman sub-categories of shrub, lignum, black box and cane-grass dominated wetlands.

For coastal wetland frequency of inundation was based on dominant vegetation type, which is governed by elevation above low tide and mean high tide levels (Table 2.3).

Table 2.3 Simplified classification of coastal wetland inundation frequency (adapted from Vanderzee1988 and Bird 1993).

Wetland type	Predictability and duration of filling	Dominant vegetation type	Frequency	Duration	Seasonalit y
Permanent	Permanently inundated lagoons and coastal lakes water stored below the low tide level.	Seagrass (*Zostra*), macro algae	Constant	Never dries	continuous
Tidal	Wet and dries twice per day on tidal cycles. Located between the low & mean high tide marks	Mudflats, Mangroves, estuarine reedbeds	Twice /day	<6 hours	continuous
Intermittent-episodic	Located above the mean high tide level but is occasionally inundated by spring tides & storm surges	Coastal saltmarsh,	3-4 times / yr	hours	Any time
Episodic	Located above the average high tide elevation & is rarely inundated by spring tides & storm surges	Swamp scrub, dune woodland	1-2 times / yr	hours	Any time

2.3 Wetland Change

The assessment of wetland vulnerability is based on a change in critical characteristics of the primary water source, particularly frequency of inundation. Climate change predictions under various scenarios are available for river flow and rainfall. Monthly river flow in many of Victoria's rivers has been modelled as part of the development of Northern Region Sustainable Water Strategies (Herron and Joyce 2008) for a number of climate change scenarios. Annual rainfall change has also been modelled. There is less information available on predicted changes in groundwater levels or rates of fluctuation. Sea level rise predictions were used to consider vulnerability of coastal wetlands, which were defined based on presence of saline tolerant/dependent vegetation.

For river flow, it is possible to calculate the change in frequency of a range of flow magnitudes and also the interval between flow events and relate this to the flows required to inundate floodplain wetlands that are reliant on river flow as their primary water source. The actual flow magnitude required to inundate a wetland is location specific and beyond the scope of this project to determine. However, we have assumed that wetlands associated with floodplain rivers would commence to fill when river flows exceed the bankfull level. The bankfull flow is the flow that typically occurs once every 1 to 2 years (e.g. Page *et al.* 2005).

For rainfall it is possible to assess the change in cumulative rainfall percentile exceedence and relate this to the likely inundation frequency of wetlands that rely on direct rainfall and local surface flow runoff.

For groundwater level it is possible to compare depth to groundwater tables in regional and local groundwater flow systems and correlate this with rainfall to determine how rapidly groundwater levels respond to changed rainfall (and hence changed recharge rates). Decline in groundwater level in response to reduced rainfall represents a risk to groundwater dependent wetlands.

For coastal wetlands vulnerability to change was based on sea level rise, although changes in freshwater inflow, groundwater and evaporation may also influence coastal wetlands.

Change in evaporation can also impact on wetland water regime by resulting in changed drying patterns with consequences for the duration of wet and dry periods (Nielsen and Brock 2009). Predictions for changes in evaporation as a result of climate change have been made (CSIRO 2007), but the specific impacts are site specific depending on local conditions like the shape and depth of individual wetlands. Moreover, other local conditions, such as prevailing wind direction also influence evaporation. Lowe *et al.* (2009) demonstrated a large degree of uncertainty in evaporation estimates depending on techniques used. These uncertainties can exceed the predicted change associated with climate change. For example, SKM estimated uncertainty in evaporation estimates at Kerang was ±37% (SKM 2010), whereas climate change is predicted to increase evaporation by an annual average of 4% (11% in winter) in the Kerang region (DSE 2009c). We discuss the implications of changed evaporation but because of the site specific issues, quantitative changes in evaporation are not incorporated into assessments of the change in water regime.

The above techniques allow an assessment of the possible change in frequency of, and interval between events that are likely to result in the inundation of different wetland types.

2.3.1 Change in inundation frequency for river fed wetlands

Modelled monthly flow data for natural and current condition and selected climate change scenarios was used. Natural conditions refer to modelled flow expected under historical climate with no water resource development. Current conditions represent current levels of water resource demand with historical climate. Climate change scenario flows were provided by DSE based on the median and stepped climate change scenarios adopted for Sustainable Water Strategy development. The baseline for assessing climate change impacts is the current condition. The inclusion of natural conditions enables an assessment of the degree of change that may have already occurred as a result of current levels of water resource development.

Using the current flows, the peak flow (in ML/month) for a range of Average Recurrence Interval (ARI) events (i.e., peak annual flow for the 1:1 year, 1:2 year, 1:5 year ARI event) for selected rivers that are known to support floodplain wetlands in each of the climate change regions was determined. The predicted ARI for each of these flow magnitudes was then calculated for the current climate and the selected climate change scenarios. Figure 2.1 shows an example plot generated using this approach for the Loddon River. Under natural conditions, the 1:1 year flow event is 30,000 ML/month (~1000 ML/day). Under current conditions this flow event occurs once every 2-3 years as a result of river regulation and extractions. Under medium climate change this event is predicted to occur once every 5 years and under stepped climate change, once every 40-50 years. In this example, the assumption is that wetlands that would have naturally experienced an inundation event once every year (seasonal wetlands) are predicted to experience a significant decrease in the frequency of inundation events under climate change in the Loddon catchment.

It should be noted that daily flow data is preferable for use in this type of analysis. This is because events that inundate wetlands typically occur at the daily rather than monthly scale. Hence monthly data can mask higher flow events that occurred for just a few days but resulted in wetland inundation. However, the modelling of climate change impacts on river flows has been undertaken at a monthly time step, not a daily time step, so data is not available to enable a daily time step analysis.

Issues with using monthly data to draw conclusions around daily events have been previously identified in environmental flow modelling. Neal *et al.* (2011) reported on techniques for, and uncertainty in, using monthly data for drawing conclusions around events that typically occur on daily time step for environmental flow studies. Short duration cease to flow events and low flow freshes were difficult to reliably assess using monthly data, but minimum baseflows, high flow freshes, bankfull and overbank flows could be more reliably assessed. Where there was a difference between the assessments on daily and monthly time steps for freshes, the assessment on a monthly time step almost always overestimated the proportion of months that the given event was actually being delivered. So the analysis is a conservative approach that may actually underestimate the impact of climate change (i.e. monthly data suggest sufficient volume was available to generate an inundation event, but daily data shows an inundation event did not occur).

Furthermore, hydrological analysis to support the Western Region Sustainable Water Strategy found a strong correlation between flow at the monthly time step and bankfull flow events (SKM unpublished data for DSE).

In the absence of daily data, monthly data was also used to demonstrate the reduction in frequency of wetland inundation for the Northern Region Sustainable Water Strategy (DSE 2009b, Herron and Joyce 2008).

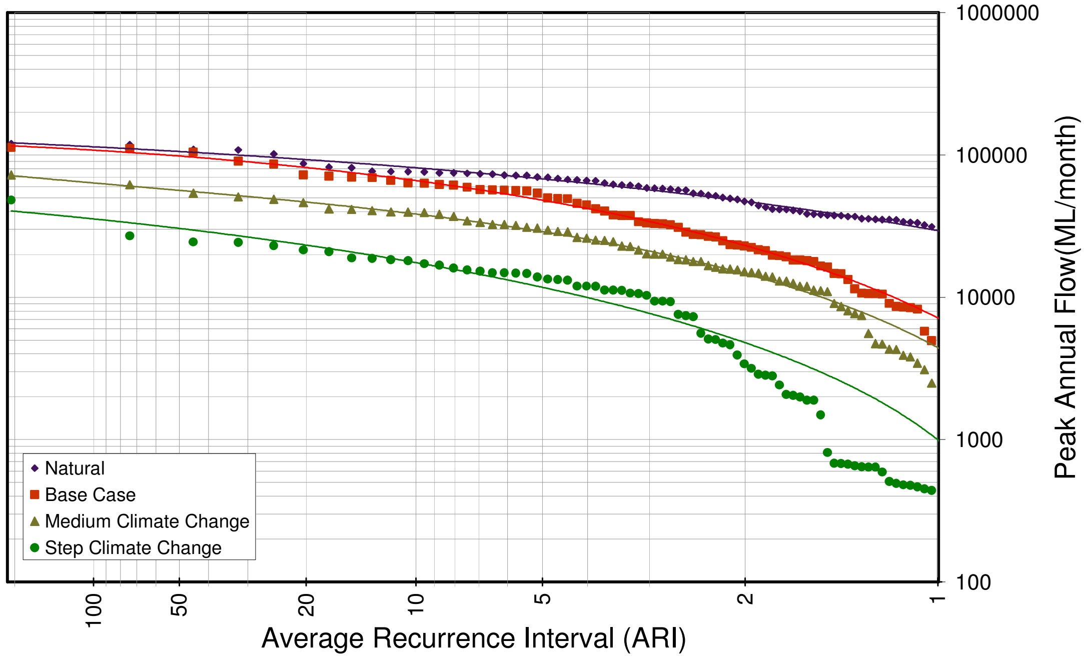


Figure 2.1 Average recurrence intervals for annual floods in the Loddon River under natural, current (Base Case) and medium and step climate change.

In addition to frequency analysis, for each system the interval between months when inundation events were predicted was also determined for natural and climate change scenarios and presented as box plots to show the change in range of interval.

River gauges selected for event frequency analysis were those that were located on river systems that supported floodplain wetlands (typically the most downstream gauge) and for which suitable climate change scenario data were available. Climate change scenario data was made available from DSE (Bill Hanson) from modelling undertaken for the development of Sustainable Water Strategies. These data were available only for regulated rivers where REALM models have been developed (Table 2.4).

Table 2.4 Regulated rivers for which modelled flow data was available.

River system	Gauge location	Source and period of data
Wimmera River	Horsham	Flows for Wimmera River – Reach 4 (REALM arcs "D/S LOCHIEL 3" and "DS DIM LOSS" for post-pipeline condition and pre-development condition models respectively) under different climate scenarios: (1) Pre-development conditions => Files "NAT1flow.ar", "NAT2flow.ar" and "NAT3flow.ar" under historical, CSIRO medium climate change @ 2055 and continuation of 1997 to 2009 inflows respectively (2) Post-pipeline conditions => Files "p608flow.ar", "u608flow.ar" and "s608flow.ar" under historical, CSIRO medium climate change @ 2055 and continuation of 1997 to 2009 inflows respectively
Loddon River	Kerang	Modelled monthly flows for the period 1891-2007 using the Goulburn Simulation Model (GSM): Natural – GOULNAT4 Base case – current system operation with historical inflows (model run D861) Medium Climate Change – current system operation with inflow restrictions based on CSIRO medium climate change predictions (model run S861) Step Climate Change - current system operation with inflow restrictions based on average reduction in stream flow 1997-2007) (model run F861)
Murray River	Euston	Modelled monthly flows for the period 1891-2007 using the REALM Murray Simulation Model (RMSM): Natural – modelled using BigMod v 3.1.9 and aggregated to monthly values Base case – current system operation with historical inflows (model run L407) Medium Climate Change – not modelled Step Climate Change - current system operation with inflow restrictions based on average reduction in stream flow 1997-2007) (model run N407)
Goulburn River	McCoys Bridge	As for Loddon
Ovens River	Peachelba East	As for Loddon
LaTrobe River	Rosedale	Modelled monthly flows from the LaTrobe River REALM model Latrobe – Reach 5, REALM arcs 330 LATR US THOMSON, 168 LD_BR NIDF2 LOSS, 180 LD_ROR NIDF2 LOSS and 95 ROSEDALE MIN FLOW
Merri River	u/s Warrnambool	Modelled monthly flows from the Merri River REALM model Merri River, Reach 5, REALM arc MERRI R 5

2.3.2 Change in inundation frequency for rain fed wetlands

We have assumed that most seasonal rain fed wetlands would be filled over a typical winter rainfall period (i.e. the median cumulative winter (June, July, August) rainfall – the winter rainfall that occurs in 50% of years or typically once every two years, i.e. where the median interval between median rainfall is one year). There will be a portion of wetlands that required more rainfall than the median winter rainfall and some that require less. However, as a broad indication of the change in frequency of the historic rainfall, we believe an analysis against the median rainfall is appropriate. To assess the impact of changed rainfall on rain fed wetlands we have calculated the historical median cumulative winter rainfall for selected rainfall gauges and then determined how often this median cumulative rainfall occurs under the various climate change scenarios. Specifically we calculate the change in interval between the median cumulative winter rainfall. Where an increase in the interval between occurrences of the median cumulative winter rainfall occurs, this indicates that rainfall that is likely to result in wetland inundation is occurring less frequently. In other words there is likely to be an increase in the duration of dry periods.

Predictions for climate changed induced change in rainfall were from Jones and Durak (2005). A scenario calculator developed as part of the Jones and Durak (2005) study was used to generate percentage change in annual rainfall under wet, medium and stepped climate change scenarios for each river basin by 2030 and 2055. This percentage factoring was then applied to historic rainfall data for selected gauges in each river basin. Basin/gauge combinations were chosen to reflect locations were mapping had identified the presence of wetlands whose primary water source was rainfall (see maps presented in relevant regional assessment sections) (Table 2.5).

Table 2.5 Rainfall gauges used in the analysis

Location (rain gauge #))	River Basin (climate region)	Period of data
Edenhope (79011)	Millicent coast (North west)	1890-2009
Mildura (76031)	Murray (North west)	1946-2009
Colac (90147)	Corangamite (South west)	1898-2009
Rocky Valley (83043)	Upper Kiewa (North East)	1951-2009
Mooroopna (81034)	Goulburn (North east)	1884-2009
Lindenow (85050)	Mitchell (South east)	1901-2009
Labertouch (85046)	Bunyip (South east)	1912-2009
Yan Yean (86131)	Yarra (South east)	1877-2009
Point Hicks (84070)	East Gippsland (Far east)	1962-2009

Historic daily rainfall used in this project was processed by a suite of programs to generate, where possible, a continuous, quality controlled time series. The recorded input data to this processing was the Bureau of Meteorology Australian Rainfall and Evaporation produced by the National Climate Centre, Melbourne. Processing was achieved through a disaggregation of accumulated data and infilling of missing data, both through relationships developed with neighbouring gauges. Disaggregation of accumulated data was achieved by adopting the daily pattern of the nearest gauge with complete record over the accumulated period, and applying this to the accumulated rainfall. Infilling of missing rainfall data was achieved through the development of annual regressions with neighbouring rainfall gauges.

As indicated above, vulnerability of rainfed wetlands is assessed as a change in the interval between rainfall events that are likely to result in wetland inundation. Figure 2.2 shows and example of how to interpret the results presented in subsequent sections. Under historical conditions, the median cumulative winter rainfall for Edenhope occurs once every 3 years (i.e. the median interval between events is 2 years). By 2030 the median interval between the median cumulative winter rainfall doesn't change, however under the dry scenario there is likely to be an increase in the duration of dry periods and indicated by the 10^{th}%ile whisker extending from 4 to 5 years (i.e. 10% of dry phases currently last for at least 4 years and these are predicted to increase to last for at least 5 years by 2030). Under the dry scenario by 2055 the median interval between the median cumulative winter rainfall is predicted to be 4 years. In other words, wetlands that are currently inundated once every 2-3 years would be inundated once every 4 to 5 years. There would also be an increase in the duration of the longest dry phases with 10% of dry phases currently lasting for at least 4 years predicted to increase to last for at least 7 years by 2055.

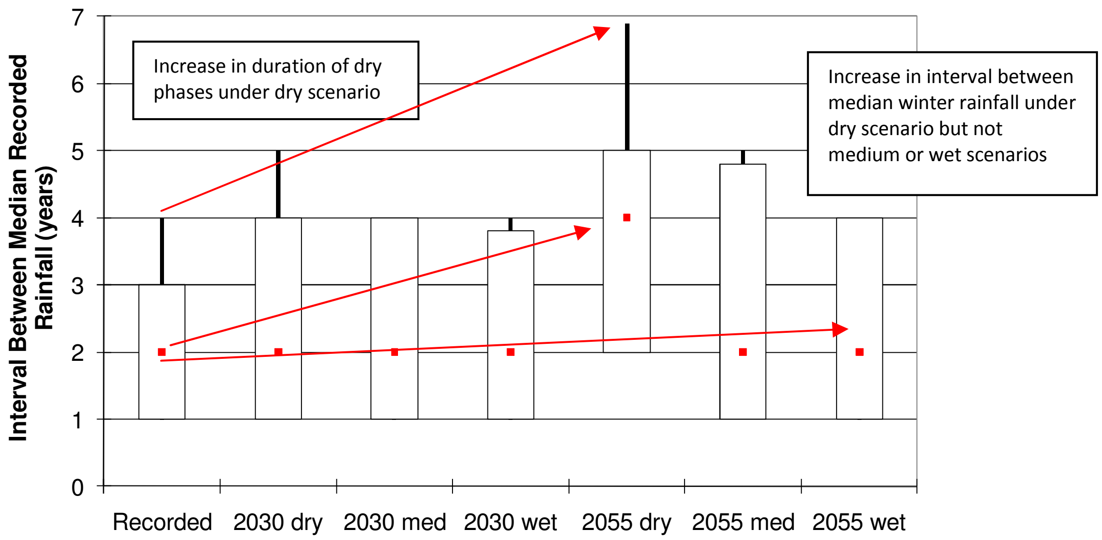


Figure 2.2 Example interpretation of rainfall interval analysis showing interval between median recorded winter rainfall (years) under climate change scenarios for Edenhope (Gauge 79011). The red spot indicates the median, the box represents the 20^{th} and 80^{th} percentiles and the whiskers the 10^{th} and 90^{th} percentiles.

2.3.3 Change in inundation frequency for groundwater fed wetlands

There are currently no regional predictions for how groundwater levels may change as a result of climate change. Hence, we have developed an approach for assessing potential impacts at a regional level based on historical correlations between rainfall and groundwater levels. The impact that changes in climate (rainfall patterns) have on the connection between groundwater and dominantly groundwater fed wetlands will vary depending on the type of wetland and the characteristics of the groundwater system which feeds it. If we consider a drying phase of climate, two examples are used to describe the extremes of the expected climatic impact.

1. *Very small, localised groundwater systems. Dominant recharge process is seasonal rainfall (localised recharge).*

   Very small groundwater systems that are driven by seasonal rainfall, will respond rapidly to changes in rainfall patterns, such that with a reduction in rainfall, groundwater levels will fall relatively quickly. This may change the nature of the connection between the groundwater system and the wetland.

2. *Very large, regional groundwater systems. Dominant recharge process is by diffuse recharge over a large region*.

   Very large groundwater systems that are driven by diffuse recharge are impacted less by short term shifts in rainfall patterns. Even during decadal long dry periods, the groundwater levels will remain relatively constant, such that the nature of connection to the wetland will remain the same.

A practical way of assessing the likely impact to groundwater fed wetlands is by investigating how the groundwater system connected to a wetland has responded to historical variations in climate. This was achieved by locating time series groundwater data that represents the groundwater system interacting with a wetland. The changes in groundwater levels compared with trends in regional climate provide an indication of how the system responds to decadal shifts in climate. If the groundwater level follows recent historical climate, then it is likely that wetlands will be impacted by future changes in rainfall patterns. If the groundwater system shows a more subdued response, indicating it is driven by much longer climatic trends (i.e. greater than 100 years), then it is less likely to be impacted by future changes in climate, at least in the short to medium term.

Across each climate region we selected a number of bores adjacent to different wetlands and compared groundwater levels with rainfall from nearby gauging locations. When identifying groundwater data, preference was given to:

- bores in close proximity to the wetlands within each climate zone;
- bores which screened the shallow aquifer (that which was in connection with the wetlands if a connection existed); and,
- those containing time series data over a period longer than 15 years (which included the wet periods of the 1990s and dry periods in the 2000s).

Where data was available, this allowed for the impact on the groundwater system of both a wetting and drying phase to be observed.

Figure 2.3 shows an example of rainfall and groundwater level trends around Natimuk in Western Victoria. Rainfall is plotted as residual monthly rainfall to show the cumulative difference in rainfall compared to the long term average since the start of the rainfall record. For each rainfall- groundwater level combination a linear regression was fitted to determine an R^2 value as an indicator of the strength of the correlation. In the example, R^2=0.97 for the period when coincident data was available (1993 onwards), indicating a direct link between rainfall and groundwater level at this location.

Groundwater data was sought for all wetland types across Victoria in order to pick up any differences in response of the associated groundwater systems at a regional scale. In some areas and hence for some wetlands, however, groundwater monitoring data was not available within a sufficient distance. This was the case for the North East and Gippsland areas, where the highland or coastal location of the majority of the wetlands coincided with sparse groundwater data that was either deemed not to be indicative of the shallow groundwater system, or of unusable temporal extent where it existed. In such cases, inferences have been made based on the results from other areas. Unfortunately, in many areas there is a lack of data that allows specification of regional or local groundwater systems, and some areas exhibit intermediate systems. In these areas groundwater systems are classified as 'regional and local' or 'regional and intermediate'. Hence the analysis is limited in its applicability in regions where groundwater systems are not well defined.

However, through this approach, it has been possible to provide a qualitative assessment of how wetlands within different landscapes may be impacted by changes in climate. The water budget of all wetlands receives direct rainfall and at least some local runoff with a dominant period of influence of groundwater to the budget during wet periods. Our assessment is based upon what would be the impact under a dry climate scenario, when influence of groundwater may be less, especially in aquifer systems that respond rapidly to changes in rainfall and hence recharge.

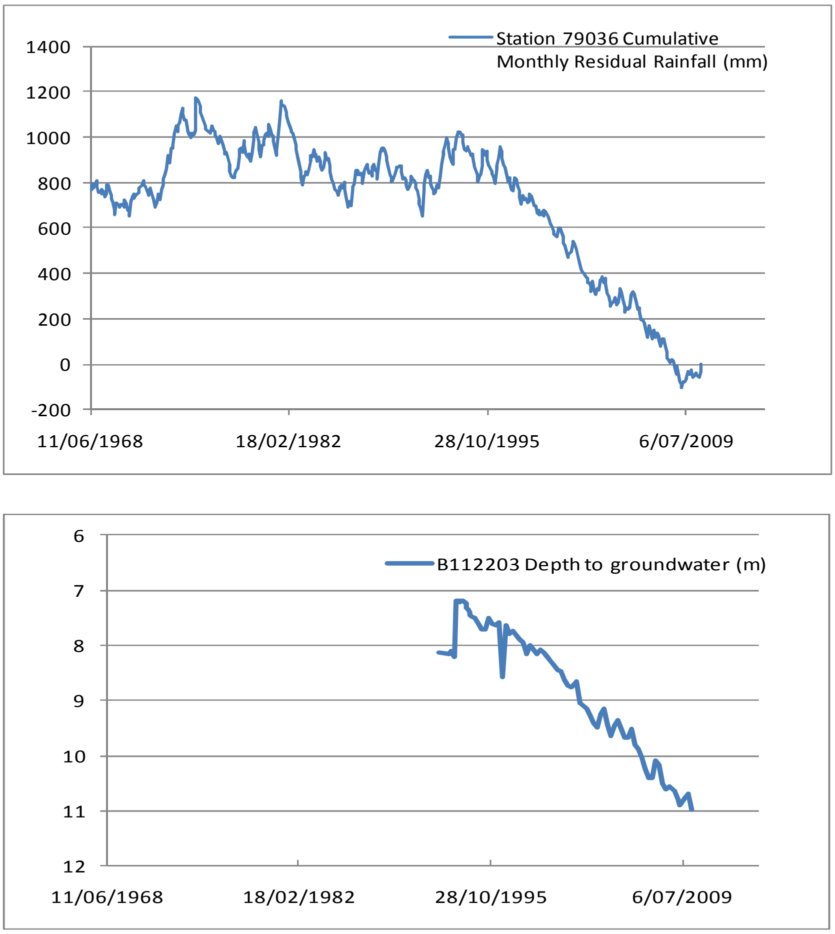


Figure 2.3 Relationship between residual rainfall at Natimuk (Station 79036) and depth to nearby groundwater. R^2=0.97 for correlation between residual rainfall and groundwater level from 1993 onwards, which represents the start of rainfall decline.

2.3.4 Change in alpine wetlands

Alpine wetlands (peatlands) are at threat from climate change due to changes in moisture availability (from changed rainfall and groundwater levels) and increased fire frequency (White, 2009). Impacts of climate change on alpine wetlands are based on the work of White (2009) who has modelled in detail the impacts of dry and wet scenarios from Jones and Durak (2005) on alpine wetlands on the Bogong High Plains. These results are presented in more detail in the results section.

2.3.5 Change in extent of coastal wetlands

The wetland mapping undertaken for this project did not map elevation or assign an elevation to coastal wetland classes. However, we have assigned a frequency of inundation to coastal wetlands based on vegetation type, and we assess vulnerability at a conceptual level based on the frequency of inundation.

2.4 Limitations

Due to the nature of available data, the uncertainty of climate change predictions and the complexity of responses there are a number of assumptions that have been made in undertaking this project. These assumptions are identified and their impact on the outcomes of the analysis are summarised in Table 2.6.

Table 2.6 Assumptions and limitations.

Assumption	Limitation	Confidence
The assessment is based on a regional scale.	Individual wetlands have not been assessed, so the assessment is indicative only	Moderate to high confidence in outcomes at a regional scale but low confidence in assessment for individual wetlands. Site specific investigations would be needed to assess impacts at the site scale.
The assessment is based on a change in frequency of inundation events.	Climate change may also alter duration, intensity and seasonality of events.	High confidence in assumption that change in frequency is a critical factor in wetland structure and function based on literature.
	Assessment does not include the impact of climate change on other variables, such as temperature, evaporation, distribution of pest species, land use change or changes in salinity.	
	Different methods have been used to the estimate effects of climate change on different water sources.	High confidence for river fed wetlands due to availability of appropriate river flows data for assessment. Low confidence for other wetland types, due to uncertainties around specific climate change impacts and lack of detailed modelling (e.g. annual rainfall used rather seasonal rainfall changes).
Assessment of change in frequency of flow or rainfall events that inundate wetlands is broadly applicable across regions for the sites chosen for analysis.	Data and modelling for selected river gauge, rainfall gauge and groundwater bore locations are intended to be representative of the impacts across the associated climate change region.	Moderate to high confidence in analysis for modelled reaches. Moderate confidence that results are broadly applicable at the regional scale, but site specific investigations are required for more detailed assessment.
Chosen scenarios provide a suitable range of conditions for assessment	Climate change scenarios from the Sustainable Water Strategies did not account for extreme events (e.g., like the recent 2010/2011 floods).	High confidence in the general trend of drying conditions and reduced stream flows under climate change. Low confidence in the frequency of specific flood events.

Table 2.6 (continued).

Assumption	Limitation	Confidence
Assumed that a change in frequency of wetland inundation translates to a change in wetlands structure and function and that the larger the change in frequency of inundation the more vulnerable a wetland becomes and the greater the likelihood that change in structure and function will occur.	Limited information on thresholds (e.g. duration of dry periods), which are likely to result in a change in wetland type, structure or function. Commence-to-fill thresholds for wetlands (either related to river flow, rainfall volume or groundwater levels) are wetland specific and beyond the scope of the current project to determine.	High confidence in assumption that change in frequency is a critical factor in wetland structure and function based on literature. Low confidence in specific thresholds. Site specific assessments would be required to provide more confidence.
Assumed that wetlands have a single water source.	Wetlands are likely to have more than one water source and different water sources are likely to dominate at different times and be important for different biota and functions.	Moderate to high confidence in outcomes at a regional scale but low confidence in assessment for individual wetlands.
Monthly flow data is sufficient to provide an indication of the pattern of flow events that inundate wetlands	Daily flow data is preferable for performing analysis on the impact the climate change has on the frequency and duration of flow events that inundate wetlands and on the interval between inundation events. However, only monthly flow data for climate change impacts on flow regimes is available.	Moderate confidence, sensitivity testing indicates that monthly data is suitable for a broad scale assessment of changed frequency of flow events. Daily data is preferred for more detailed analysis.
Mapping of wetland type is accurate	The layers used to assign primary water source were derived from existing databases, previous literature reviews and knowledge of the project team members on which systems. Mapping is known to be inaccurate.	Moderate confidence in overall regional patterns and distribution of wetland types, but low confidence at the individual wetland.

3. Results

3.1 Climate Change

3.1.1 Scenarios

A review of existing climate change scenarios and consultation with DSE climate change specialists was undertaken. To account for the likely uncertainty in the climate change predictions for inland wetlands it was decided to adopt two distinctly different climate change scenarios. Within the envelope of climate change predictions the scenarios selected represent two ends of the spectrum:

1. A dry scenario based on current system operation with inflow reductions based on average changes in stream flows from 1997-2007 (i.e. step climate change model run F861). This is equivalent to Scenario D (Continuation of recent inflows) used in the Victorian Sustainable Water Strategies; and
2. A wet scenario based on current system operation with inflow reductions based on CSIRO medium climate change predictions using CSIRO 2005 estimates to 2055 and baseline 1890 – 2010 (model run S861). This scenario is equivalent to Scenario B (medium scenario) used in Victorian Sustainable Water Strategies.

For sea level rise the A1FI coastal scenario – 0.8 m sea level rise by 2100 from the Future Coasts Program was adopted.

These scenarios are consistent with those used by DSE for Sustainable Water Strategy planning.

3.1.2 Regionalisation

The review of climate change information and consultation with climate change specialists led to the development of five climate change regions for Victoria (Table 3.1 and Figure 3.1).

Table 3.1 Climate regions and associated river basins.

Climate region	Associated river basins
North west	Campaspe, Loddon, Avoca, Mallee, Wimmera-Avon, Millicent Coast
North east	Goulburn, Broken, Ovens, Kiewa, Mitta Mitta, Upper Murray
South west	Glenelg, Portland Coast, Hopkins, Barwon, Lake Corangamite, Moorabool, Werribee, Maribyrnong
South east	Yarra, Western Port, Latrobe, South Gippsland, Thompson, Avon, Mitchell, Tambo, Otway
Far east	Snowy, Far East Gippsland, Towamba

Under climate change the west of the State is likely to become drier than the east. In the far east, climate change is unlikely to result in significant drying. There is also an obvious divide in expected climate change impacts in northern and southern Victoria with the north likely to become drier than the south of the State.

The East Gippsland and Snowy basins were separated out as a region because they are likely to be more subject to the influence of east coast low pressure systems. The Otway basin has been grouped with the South east climate change region as changes in this basin are more closely aligned with this region rather than other south west regions due to less significant changes in rainfall.

Specific regional effects of climate change on rainfall and river flow are presented in the following sections on wetland changes.

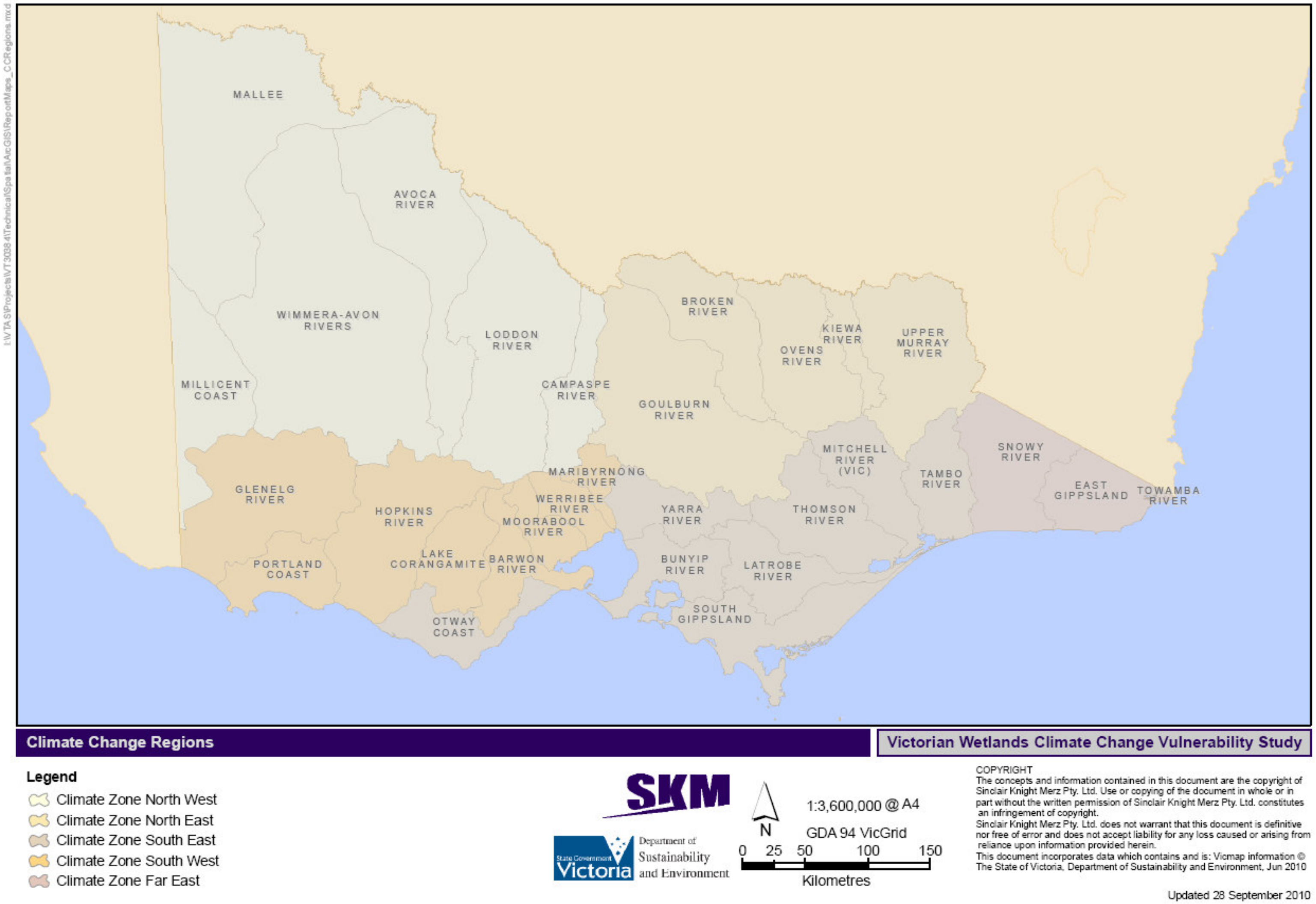


Figure 3.1 Climate change regionalisation for Victoria.

3.2 Wetland Vulnerability

3.2.1 State overview of current wetland extent

Figure 3.2 summarises the area and number of wetlands across the State by primary water source (including saline versus fresh) and estimated current frequency of inundation (Appendix B.1)**0** provides more detail on area, number and percentages). The State wetlands inventory compiled for this project included over 20,000 wetlands with a total area of greater than 480,000 Ha. River fed wetlands make up the largest number (~7700 or ~38%) of wetlands and also the greatest area (~206,600 Ha or ~42%). Rainfall fed wetlands are the next most numerous at 36% by number, but only represent 12% of wetlands by area with groundwater fed and coastal wetlands contributing an overall larger area. Seasonal wetlands (shallow freshwater marshes and freshwater meadows) are the most common wetland type, representing 71% by number and 47% by area of the State's wetlands. Permanent wetlands represent 22% by number and 40% by area. The majority of the groundwater fed wetlands (by area) are saline, although by number there are more freshwater groundwater fed wetlands than saline wetlands.

Of the coastal wetlands, around 60% are considered intermittent, that is they are located above the mean high tide level and are inundated several time a year on spring tides and storm surges. Permanent systems comprising saline lagoons and lakes connected to the marine environment represent around 15% by number of coastal wetlands but around 52% of total coastal wetland area.

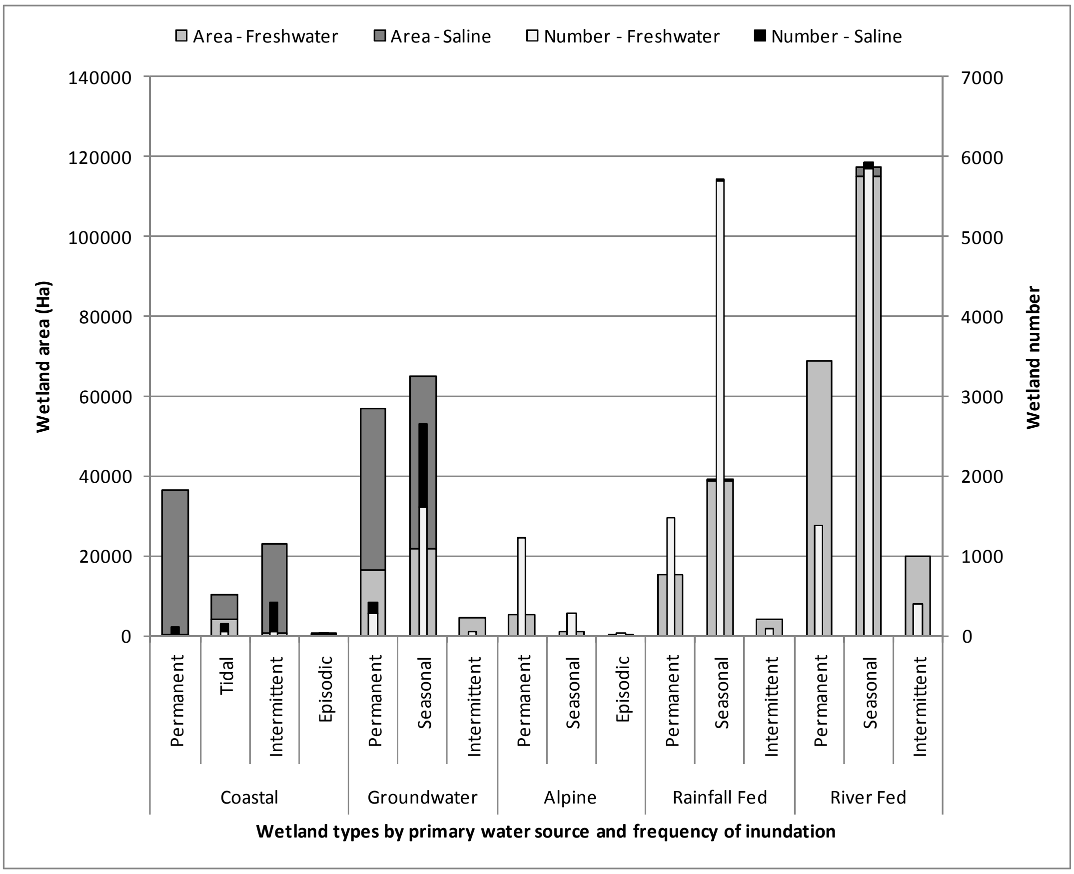


Figure 3.2 Area and number of wetland types by primary water source and current frequency of inundation across Victoria

3.2.2 North west region

Figure 3.3 summarises the number and area of the wetlands in the north west region (shown in Figure 3.4) by primary water source and frequency of inundation. Appendix B.2 provides more detail on area, number and percentages. River fed wetlands make up the largest number of wetlands and also the greatest area. Most river fed wetlands are seasonal shallow freshwater marshes and freshwater meadows, although permanent freshwater wetlands make up the largest area (e.g. the Kerang Lakes in the Loddon catchment). As a percentage of the total number and area across the whole state, groundwater fed wetlands in this region represent nearly 50% of the states groundwater wetlands by number and area, although this may be an overestimation, as many wetlands in the Wimmera region have been more correctly designated as rainfall fed (SKM 2006). Semi-permanent (seasonal) saline wetlands represent the largest area of groundwater fed wetlands. A large number (although small in area) of rainfall fed wetlands are located in the Millicent Coast drainage basin in the south west of the region; these are predominantly seasonal shallow freshwater marshes and freshwater meadows.

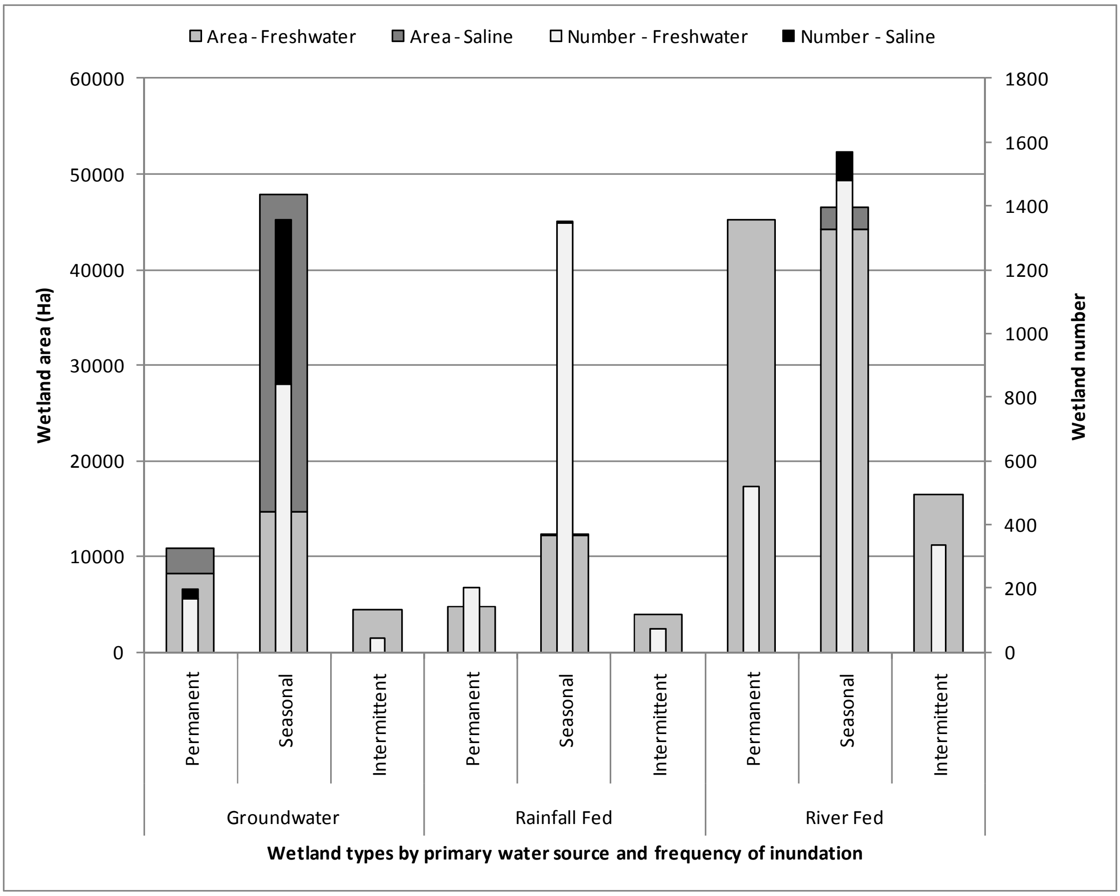


Figure 3.3 Number of wetland types by primary water source and current frequency of inundation

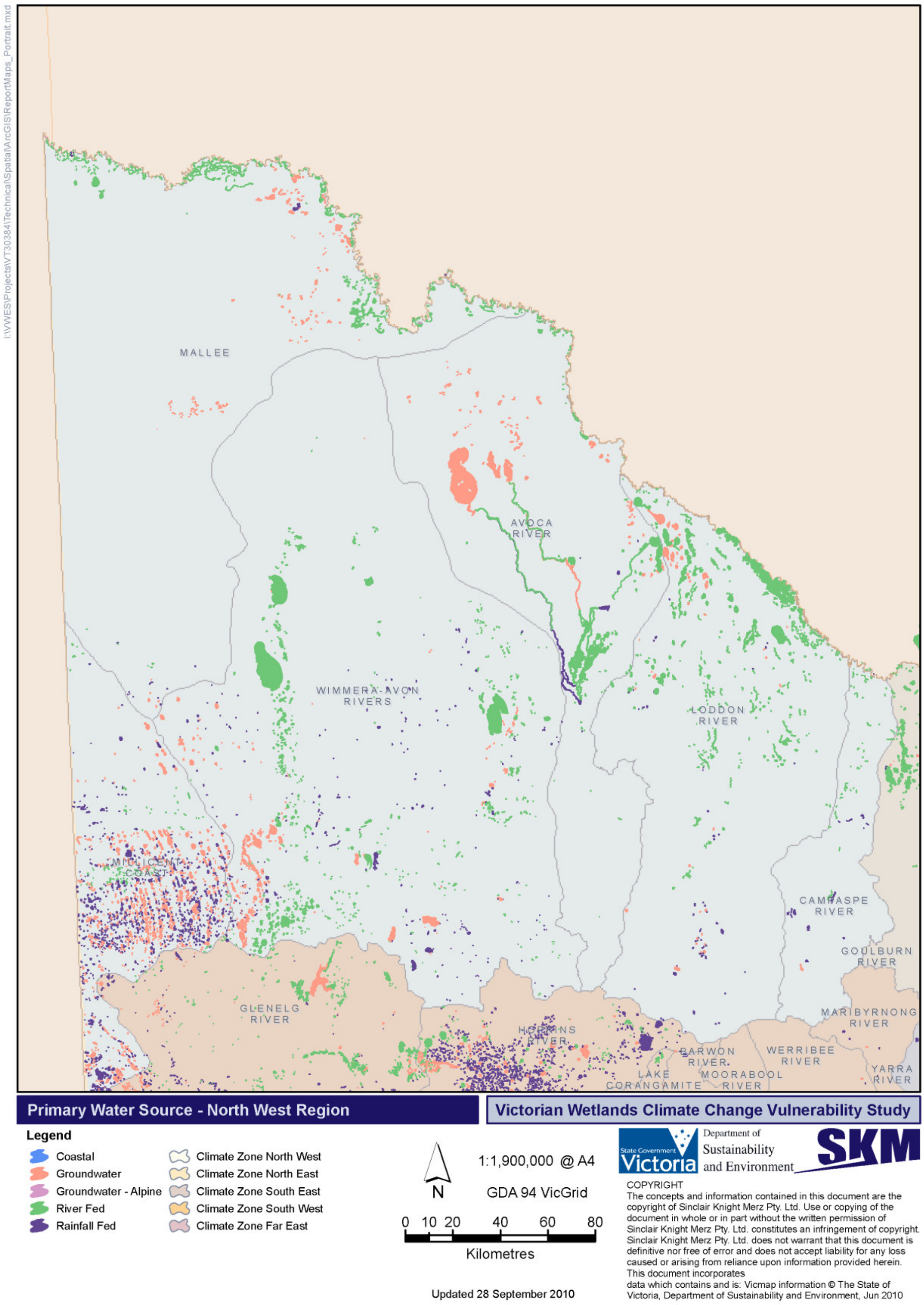


Figure 3.4 North west wetlands by primary water source

3.2.2.1 River fed wetlands

For river fed wetlands, the Wimmera River at Horsham, Loddon River at Kerang and Murray River at Euston were used to assess the change in frequency of wetland inundation predicted to occur in the north west region. The analysis of the impacts of climate change on the frequency of river flows is consistent with that undertaken for assessing the impacts of climate change on wetlands for the Northern Region Sustainable Water Strategy (see Herron and Joyce, 2008 and DSE 2009b). The analysis provides a range of outcomes that defines the least impact scenario (equivalent to current condition and the worst case scenario (equivalent to stepped climate change). The reality is likely to be somewhere in between (i.e., the medium climate change scenario). Modelling has not been undertaken for the Avoca or Campaspe Rivers in the north west region because modelled data suitable for analysis was not available at the time.

Wimmera River catchment

Within the Wimmera River parts of the region climate change is predicted to have a major effect on river fed wetlands. Analysis of the change in frequency of inundation indicates that wetlands that would be inundated every year under historic river flows (pre-Wimmera-Mallee Pipeline) are predicted to be inundated once every 2.5 years under a medium climate change scenario and wetlands inundated once every 3 years under historic flows may be inundated just once every 20 years (Table 3.2 and Figure 3.5). Under stepped climate change it is predicted that flows equivalent to the historical 1:1 year recurrence interval may not occur again.

Table 3.2 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared to Average Recurrence Intervals under natural conditions for the Wimmera River at Horsham.

Frequency of inundation	Flow (ML/month)	Average recurrence interval – natural historic climate conditions	Equivalent Average Recurrence Interval – Base Case (current levels of demand historic climate)	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	35,000	1:1	1:1.5	1:2.5	>1:100
Seasonal	84,000	1:2	1:3	>1:10	>1:100
	100,000	1:3	1:4	>1:20	>1:100
Intermittent	130,000	1:5	1:9	>1:50	>1:100
	170,000	1:10	1:15	>1:100	>1:100

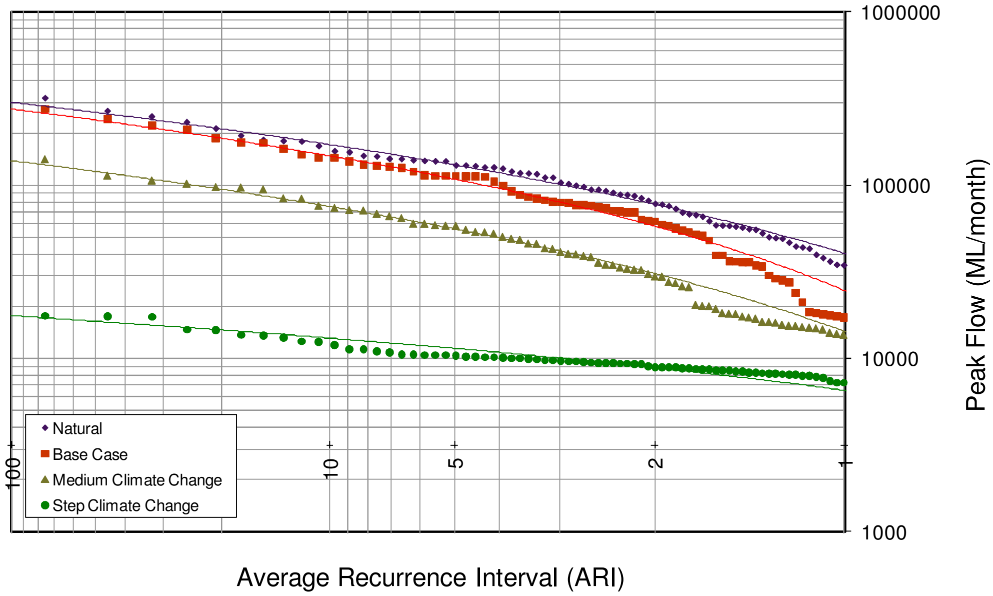


Figure 3.5 Average recurrence intervals for a range of flows in the Wimmera River under natural, current (Base Case) and medium and step climate change.

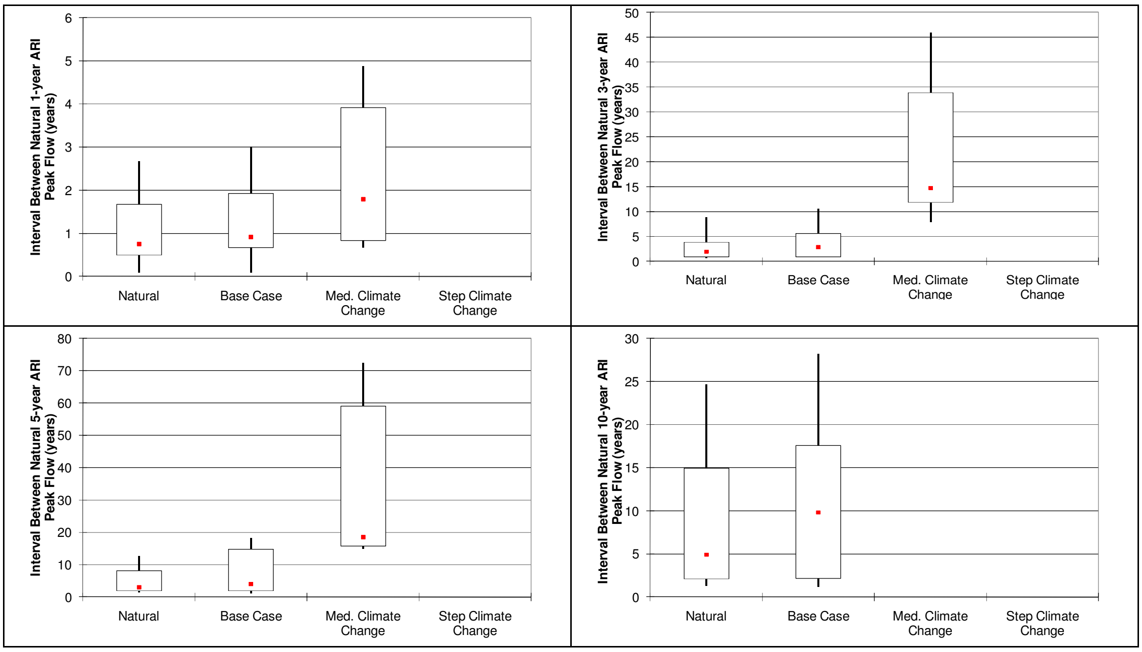
In addition to a reduction in the frequency of events that inundate seasonal wetlands, the interval between inundation events is predicted to substantially increase. For example, the median interval between the historical (natural) 1:3 year event is 1.9 years. This is expected to increase to 15 years under medium climate change (Table 3.3 and Figure 3.6).

Post Wimmera-Mallee Pipeline modelling was not used in the assessment, but the benefits of the pipeline in terms of increased river flows may result in a slight mitigation of the impact of climate change. This may apply particularly for the terminal lakes system (Lakes Hindmarsh and Albacutya), which are more likely to receive water if longer duration flows occur in the lower Wimmera River, as predicted post-pipeline..

Table 3.3 Median and 90th%ile interval (years) between events for range of ARI events under various scenarios for the Wimmera River at Horsham.

ARI flow event	Percentile	Interval (years) between events for each scenario			
		Natural	BaseCase	Med CC	Step CC
1:1 year	Median	0.8	0.9	1.8	-
	90th%ile	2.7	3.0	4.9	-
1:3 year	Median	1.9	2.8	14.8	-
	90th%ile	8.7	10.5	45.9	-
1:5 year	Median	3.0	4.0	18.6	-
	90th%ile	12.7	18.5	72.5	-
1:10 year	Median	4.9	9.8	-	-
	90th%ile	24.7	28.3	-	-

- Event no longer predicted to occur



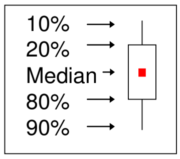


Figure 3.6 Box plot showing change in interval between events in the Wimmera River at Horsham to demonstrate the effect of climate change on the interval between events that will inundate seasonal wetlands.

Loddon River catchment

In the Loddon catchment flows that currently occur once every year are predicted to occur once every five years under medium climate change and once every 50 years under step climate change (Table 3.4 and Figure 3.7). The interval between events also gets greater (Table 3.5 and Figure 3.8). Flows that occur every 5 years are predicted to not occur under either medium or step climate change.

Table 3.4 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared Average Recurrence Intervals under natural conditions for the Loddon River.

Frequency of inundation	Flow (ML/month) equivalent to the natural historic climate ARI	Average recurrence interval – natural historic climate conditions	Equivalent Average Recurrence Interval – current levels of demand historic climate	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	30,000	1:1	1:2.5	1:5.5	1:50
Seasonal	48,000	1:2	1:5	1:20	>1:100
	56,000	1:3	1:7	1:40	>1:100
Intermittent	70,000	1:5	1:12	>1:100	>1:100
	80,000	1:10	1:20	>1:100	>1:100

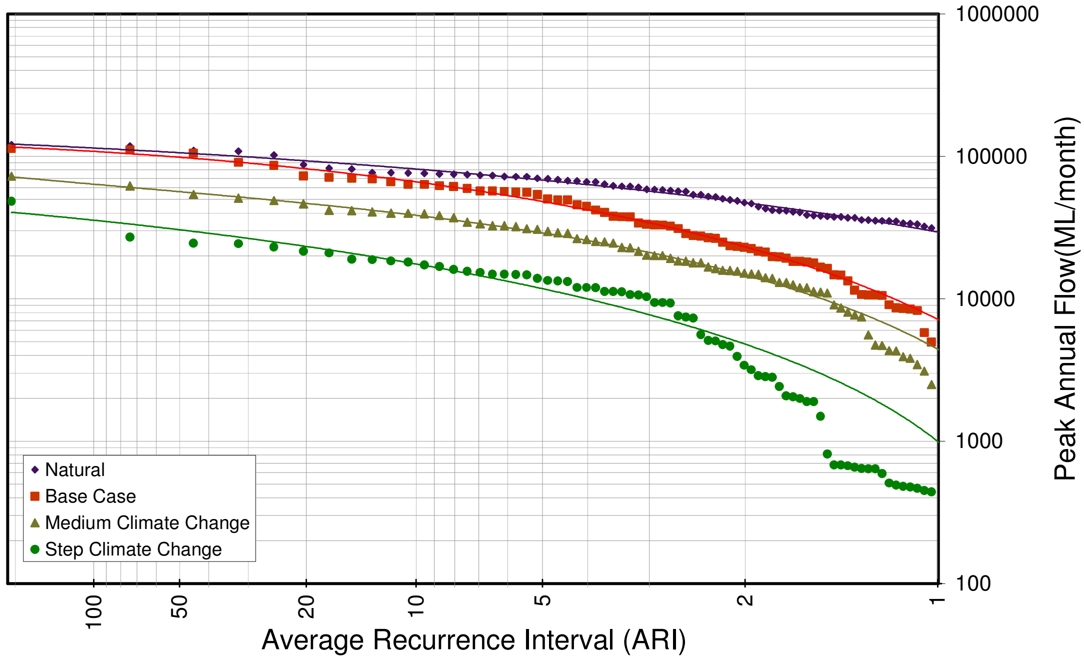
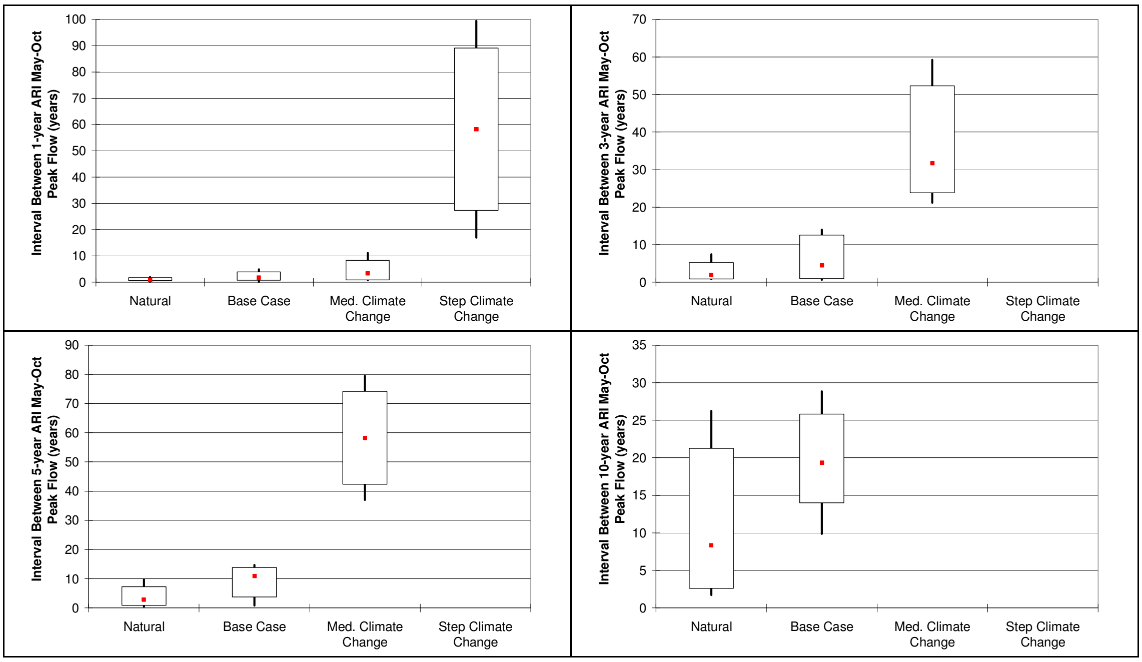


Figure 3.7 Average recurrence intervals for annual floods in the Loddon River under natural, current (Base Case) and medium and step climate change.

Table 3.5 Median and 90th%ile interval (years) between events for range of ARI events under various scenarios for the Loddon River.

ARI flow event	Percentile	Interval (years) between events for each scenario			
		Natural	BaseCase	Med CC	Step CC
1:1 year	Median	1	1	3	59
	90th%ile	2	5	11	100
1:3 year	Median	2	3	33	-
	90th%ile	8	15	59	-
1:5 year	Median	3.0	11	59	-
	90th%ile	10	15	79	-
1:10 year	Median	8	18	-	-
	90th%ile	27	28	-	-

- Event no longer predicted to occur



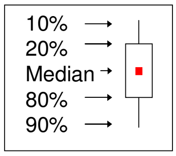


Figure 3.8 Box plot showing change in interval between events in the Loddon River to demonstrate the effect of climate change on the interval between events that will inundate seasonal wetlands.

Murray River at Euston

Table 3.6 and Figure 3.9 present the changes in frequency of a range of flow events for the Murray River at Euston under natural current and stepped climate change estimates. The flow that would have naturally occurred once per year now occurs once every 4 years as a result of the impacts of upstream extraction and flood mitigation. Under stepped climate change this flow is predicted to occur once every 80 years. Flows that naturally occurred once every 5 years now occur once every 18 years and are predicted to occur less frequently than once every 100 years under stepped climate change. The interval between events also gets greater (Table 3.7 and Figure 3.10). Note, a wet scenario was not analysed for the Euston gauge because modelled flows were not available.

Table 3.6 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared Average Recurrence Intervals under natural conditions for the Murray River at Euston.

Frequency of inundation	Flow (ML/day) equivalent to the natural historic climate ARI	Average recurrence interval – natural historic climate conditions	Equivalent Average Recurrence Interval – current levels of demand historic climate	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	55,000	1:1	1:4	na	1:80
Seasonal	84,000	1:2	1:8	na	>1:100
	103,000	1:3	1:12	na	>1:100
Intermittent	137,000	1:5	1:18	na	>1:100
	148,000	1:10	1:30	na	>1:100

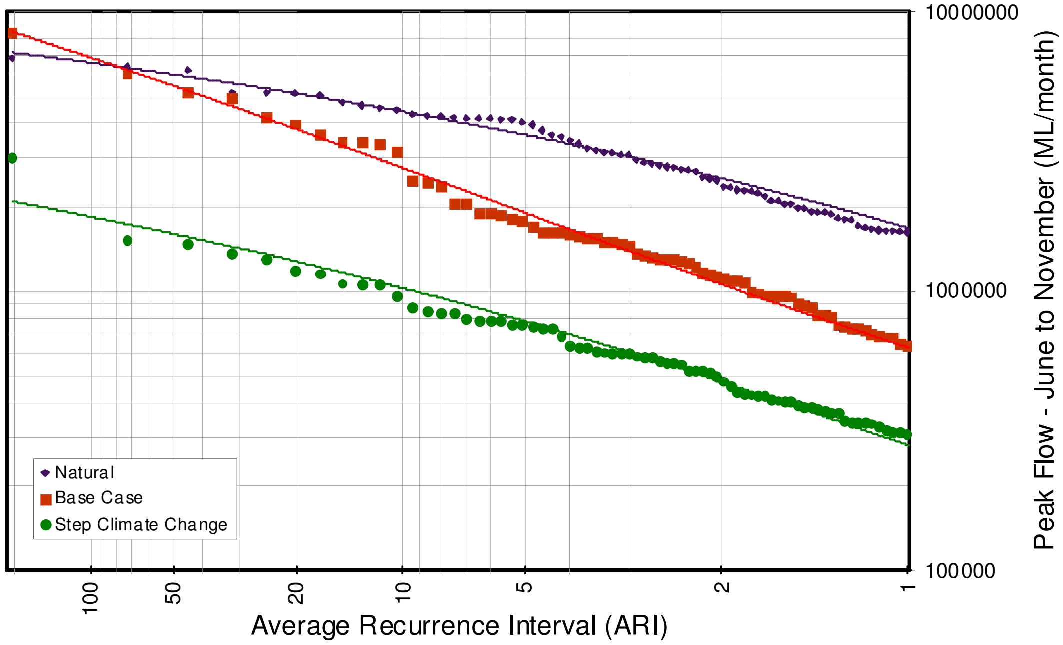
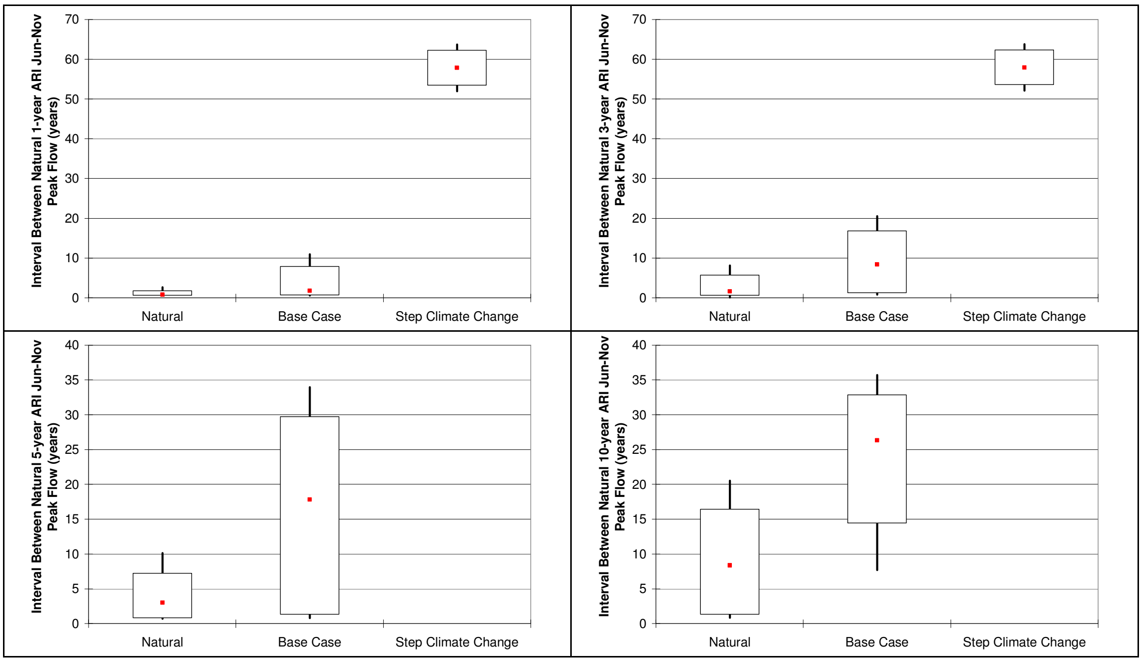


Figure 3.9 Average recurrence intervals for annual floods in the Murray River at Euston under natural, current (Base Case) and step climate change.

Table 3.7 Median and 90th%ile interval (years) between events for range of ARI events under various scenarios for the Murray River at Euston.

ARI flow event	**Percentile**	**Interval (years) between events for each scenario**			
		Natural	**BaseCase**	**Med CC**	**Step CC**
1:1 year	Median	0.8	1.8	na	58
	90th%ile	3	11	na	64
1:3 year	Median	1.7	8	na	58
	90th%ile	8.1	21	na	64
1:5 year	Median	3	18	na	-
	90th%ile	10	34	na	-
1:10 year	Median	8.4	26	na	-
	90th%ile	21	36	na	-

- Event no longer predicted to occur



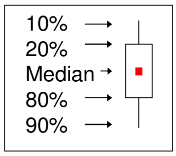


Figure 3.10 Box plot showing change in interval between events in the Murray River at Euston to demonstrate the effect of climate change on the interval between events that will inundate seasonal wetlands.

3.2.2.2 Rainfall fed wetlands

The majority of rainfall fed wetlands lie in the western part of the region, known as the Millicent Coast catchment (Figure 3.4). In this area the change in frequency of inundation events is less significant than for nearby river fed wetlands. Across the region annual rainfall is predicted to decline from east to west with the largest reduction in rainfall predicted for the Wimmera and Millicent Coast basins at 16% and 17% respectively by 2055 under the dry scenario (Table 3.8).

Table 3.8 Percentage reduction in annual rainfall under dry and medium climate scenarios for 2030 and 2055 (note, long term rainfall predictions are for 2055 compared with flow predictions which are for 2050).

Basin	Rainfall gauge (#)	2030		2055	
		Dry	Med	Dry	Med
Campaspe		-7.3%	-4.2%	-15.5%	-8.7%
Loddon		-7.2%	-4.2%	-15.2%	-8.8%
Avoca		-7.1%	-3.8%	-14.9%	-8.0%
Mallee	Mildura (76031)	-7.2%	-3.0%	-15.3%	-6.3%
Wimmera-Avon		-7.5%	-4.6%	-16.0%	-9.6%
Millicent Coast	Edenhope (79011)	-8.0%	-4.6%	-17.0%	-9.5%

At Edenhope, in the Millicent coast basin, rainfall is expected to decrease by up to 17% under the dry scenario by 2055. The median interval (years) between occurrence of the median recorded winter rainfall total (currently 207 mm over the winter period) is not expected to change between now and 2030 under climate change, although the maximum interval between years when the median winter rainfall occurs is expected to increase, particularly under the dry scenario where a 17% reduction in rainfall is predicted (Figure 3.11). In other words, winter rainfall sufficient to inundate most rain fall fed wetlands will continue to occur in most years, but under the drier climate change scenarios there is likely to be an increase in the duration of some drier periods. However, by 2050, there is predicted to be a more substantial increase in the interval between median recorded winter rainfall, especially for the dry scenario and to a lesser degree the medium scenario. Under the dry scenario, wetlands that are currently inundated once every 1 to 2 years based on median winter rainfall may only be inundated once every 4 years. In this region there will be a shift in wetland type from seasonal wetlands to more intermittent wetlands. Under a dry climate scenario this shift will occur more rapidly (within the next ten to twenty years), compared to a wetter climate scenario which may take fifty years for the shift to occur.

Further north, around Mildura, rainfall reductions are of a similar percentage as at Edenhope (up to 16% reduction for the dry scenario by 2055). However, climate change is not predicted to have as great an impact on rainfall (Figure 3.12). This is because median winter rainfall is already very low in this region (72 mm over the winter period), so the percentage reduction translates to a relatively small absolute reduction in rainfall volume.

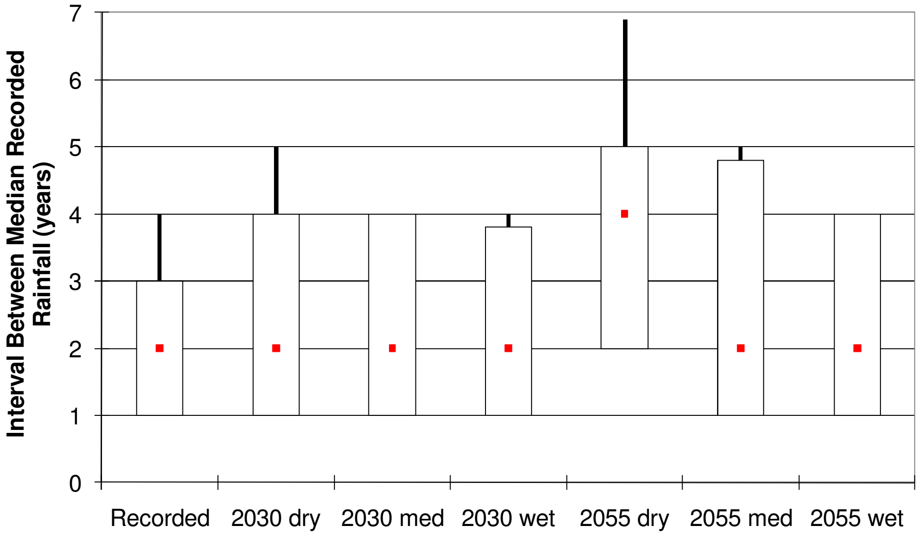


Figure 3.11 Interval between median recorded winter rainfall (years) under climate change scenarios for Edenhope (Gauge 79011).

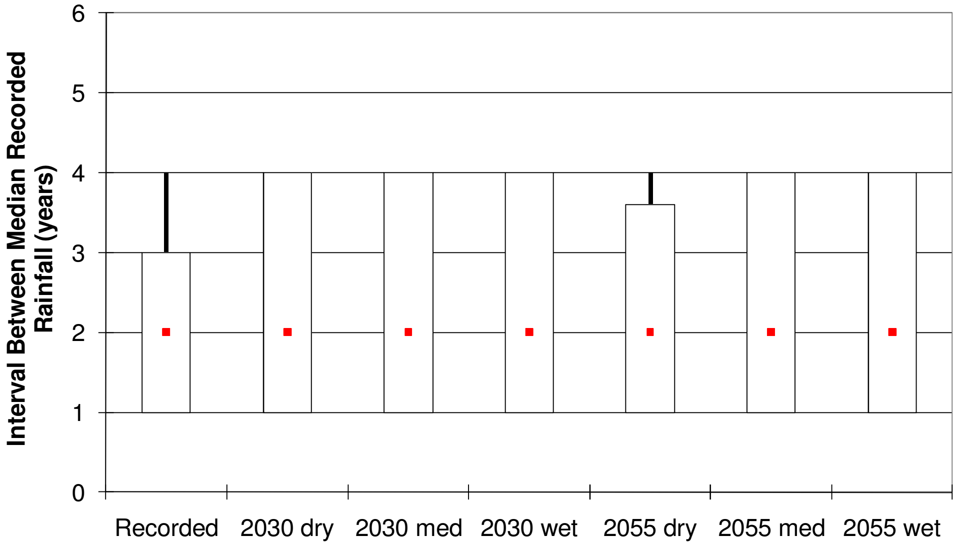


Figure 3.12 Interval between median recorded winter rainfall (years) under climate change scenarios for Mildura (Gauge 76031).

3.2.2.3 Groundwater fed wetlands

Wetlands that access groundwater that are associated with regional scale groundwater flow systems are less likely to experience a change in the frequency of inundation compared to wetlands that are associated with local scale groundwater flow systems. Regional scale systems around Sea Lake, in the north west of the Avoca Basin, show that over the past 20 years there has been a continual decline in cumulative rainfall but this has not translated to a similar decline in the depth to groundwater. The data show depth to groundwater to have very remained relatively constant since records began in 1968. There is very slow decline in level since 1978, but the correlation with declining rainfall over the same period is weak (R^2=0.28) (Figure 3.13).

However, further south in the Millicent Coast catchment where local groundwater flow systems occur, there is a much stronger correlation (R^2=0.97) between reduced rainfall and falling depth to groundwater (Figure 3.14). Here, within the Douglas Depression for example, depth to groundwater data show levels to have varied significantly over the monitoring period. Depths have increased by over 3.5 m since the mid 1990s. This decline corresponds with reductions in rainfall over the same period, which suggests the groundwater system to be sensitive to decadal changes in climate. These wetlands may continue to receive surface run off from local rainfall, but the duration of inundation is likely to decrease if they become disconnected from the groundwater system. They may also dry out more quickly, even if inundated by rainfall, due to high recharge flux rates once groundwater levels fall.

Saline groundwater fed wetlands are fewer in number but larger in area than the freshwater wetlands. It is uncertain whether climate change will result in a change in salinity of the groundwater at a regional scale and hence whether there would be a significant shift in salinity of groundwater fed wetlands. However, as indicated above, falling groundwater levels might result in a reduced frequency of inundation and a shift from permanent to more seasonal or intermittent wetlands. This could cause an increase in salinity due to evaporation in wetlands that dry out more quickly.

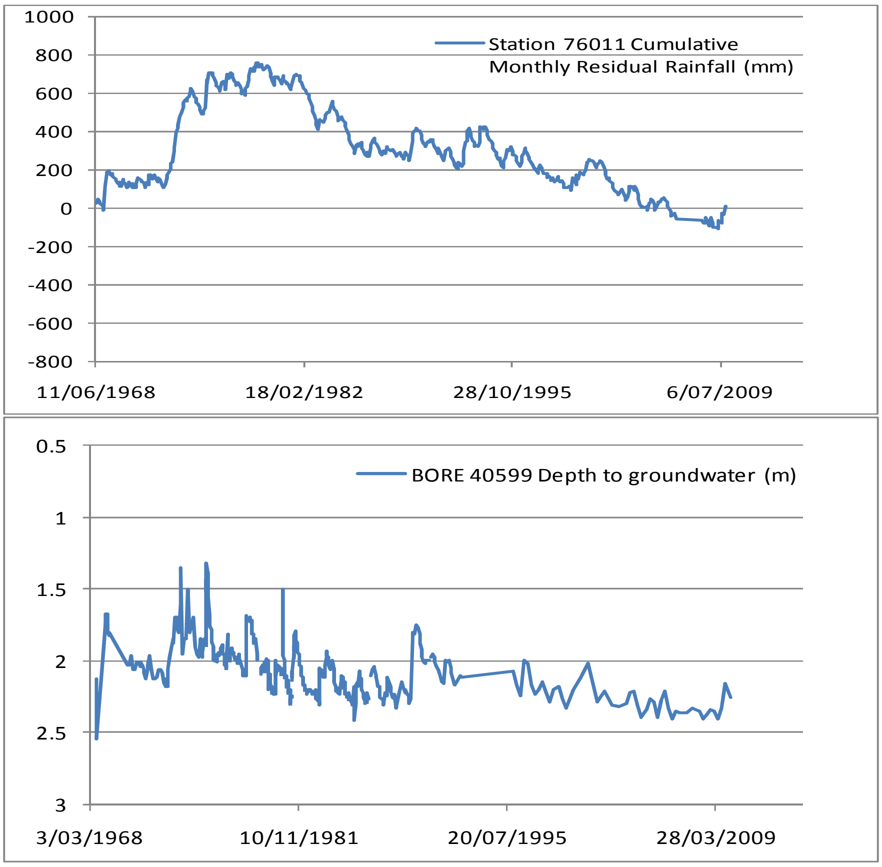


Figure 3.13 Relationship between residual rainfall at Manangatang (Station 76011) and depth to nearby groundwater. R^2=0.28 for correlation between residual rainfall and groundwater level from 1978 onwards, which represents the start of rainfall decline.

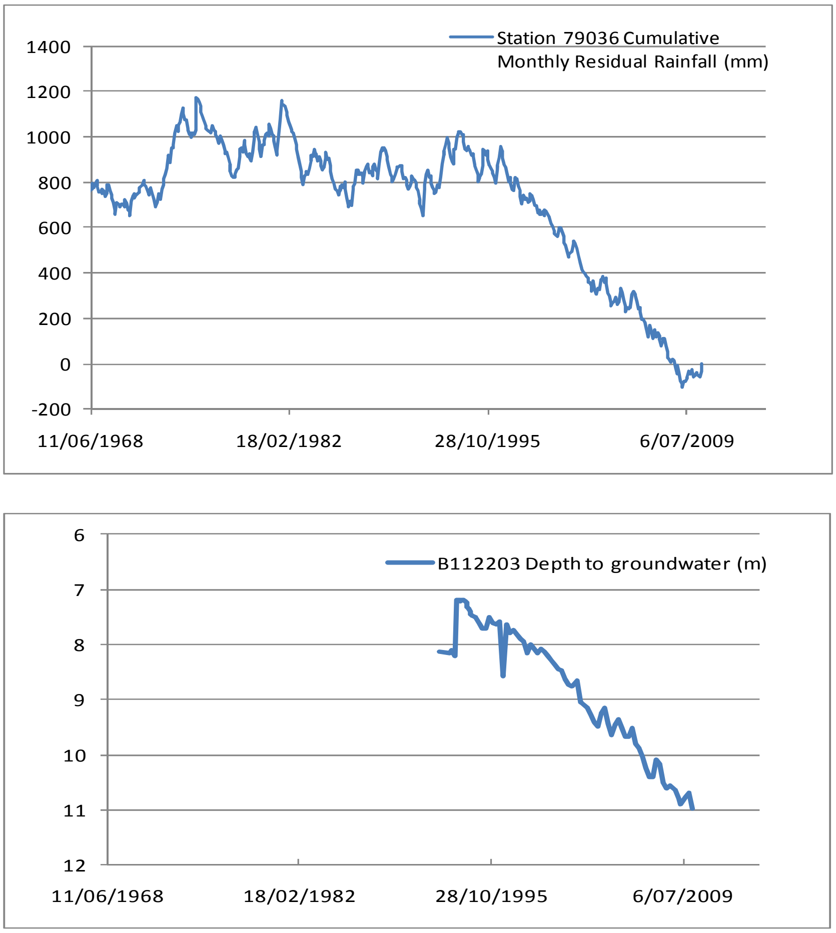


Figure 3.14 Relationship between residual rainfall at Natimuk (Station 79036) and depth to nearby groundwater. R^2=0.97 for correlation between residual rainfall and groundwater level from 1993 onwards, which represents the start of rainfall decline.

3.2.2.4 Summary for north west region

In summary, for the north west region, river fed wetlands along the major river systems for which modelling has occurred (Wimmera, Loddon, and Murray) are likely to experience a reduction in the frequency of events that inundate wetlands that would have historically experienced seasonal inundation around once every one to three years. Modelling predicts that under step climate change there will be no inundation events. However, under less severe climate change predictions (i.e. the medium scenario) wetland inundation will continue to occur but at a reduced frequency.

The river fed wetland most at risk are the seasonal wetlands that experience inundation every 1 to 3 years. In the north west region, season river fed wetlands (shallow freshwater marshes and freshwater meadows) account for 65% of the total number of river fed wetlands, 24% of all wetlands in region by number and 19% of all wetlands in the region by area. The reduction in the frequency of inundation of these regularly inundated seasonal floodplain wetlands will result in a shift to more wetlands with an intermittent watering regime. However, it is difficult to specify the exact number or area of wetlands that will experience this shift. This shift is likely to result in a reduction in the diversity of aquatic and semi-aquatic plant species and an increase in terrestrial species that are tolerant of occasional flooding rather than those that are dependent on flooding (see the general discussion in Section **0** for details on how wetland ecology is predicted to change).

Rainfall fed wetlands are mostly located in the south west of the region in the Millicent Coast and Wimmera catchments. Under the worst case scenario, median winter rainfall is predicted to decline by around 17% by 2050 under the dry scenario. This will result in an increase in the interval between inundation events from around once every 1 to 2 years to once every 4 years. However, other scenarios will result in a less dramatic decline in frequency of inundation and rain fed wetlands should continue to persist in the landscape.

Wetlands that access groundwater that is associated with regional scale groundwater flow systems are less likely to experience a change in the frequency of inundation compared to wetlands that are associated with local scale groundwater flow systems where a reduction in rainfall translates to a fall in groundwater levels below the bed level of most wetlands. The region supports a large number of seasonal groundwater fed wetlands. However, it is unclear the proportions that are located within local or regional groundwater systems. Also, many of these wetlands will also receive inundation via rainfall and local catchment runoff, so changes in the specific water regime are difficult to determine. However, similar to river fed wetlands, climate change is likely to result in a shift in the water regime from seasonal to intermittent for at least some of these wetlands (particularly those with a very strong groundwater association) with consequent changes in wetland ecology, particularly vegetation community structure.

3.2.3 South west region

Figure 3.15 summarises the area and number of wetlands in the south west region by primary water source and frequency of inundation and. Figure 3.16 shows a map of wetlands in the south west region by primary water source. Appendix B.3 provides more detail on area, number and percentages. Rainfall fed wetlands, particularly freshwater meadows, make up the largest number of wetlands, but groundwater fed wetlands make up the largest area. As a region, the south west supports 45% (by number) of all rain fed wetlands in the State and 40% (by number) of all groundwater fed wetlands. Seasonal wetlands make up the greatest proportion of wetlands (85% by number), followed by permanent wetlands (11% by number). However, permanent wetlands make up the largest area of wetlands (55% by area), with the majority of these considered groundwater fed in the Corangamite Basin.

The south west region also supports coastal wetlands, the majority of which are considered intermittent, that is they experience marine inundation several times a year associated with spring tides and storm surges. The majority of these wetland types are coastal saltmarsh. As a percentage of the state, the south west region supports 19% by number, but just 9% by area of the State's coastal wetlands.

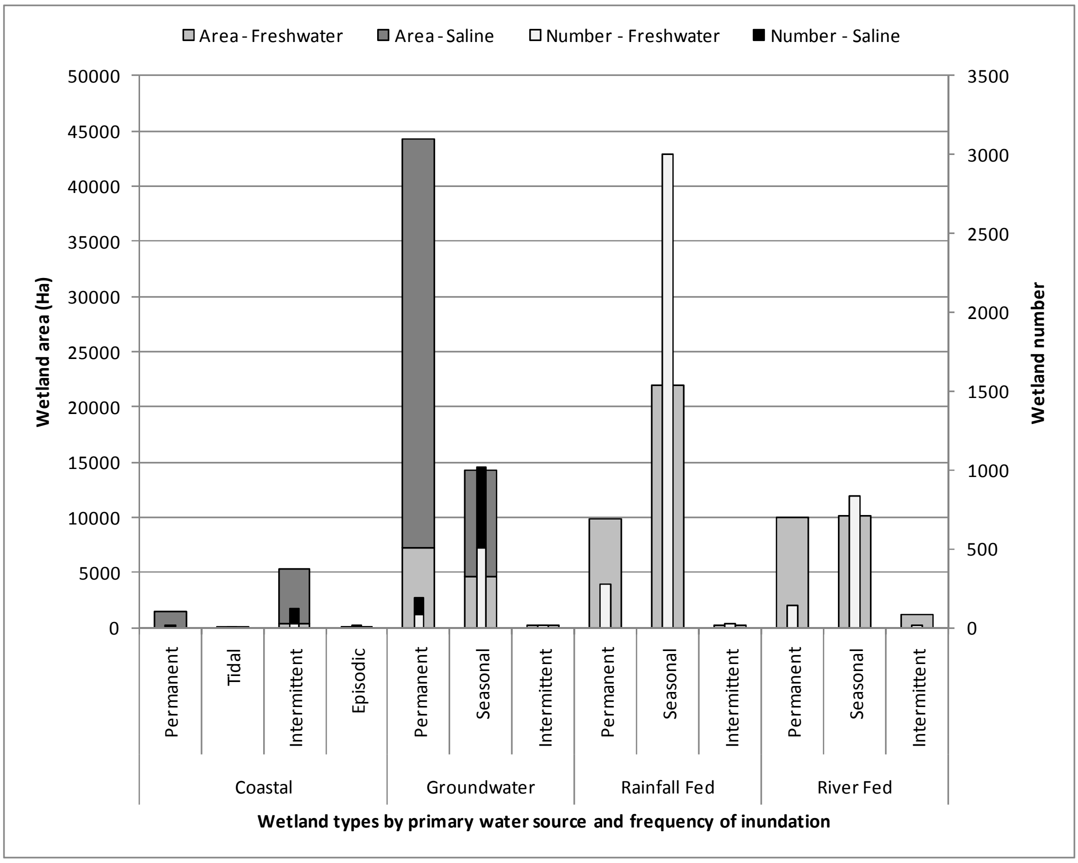


Figure 3.15 Area and number of wetland types by primary water source and current frequency of inundation in the south west region.

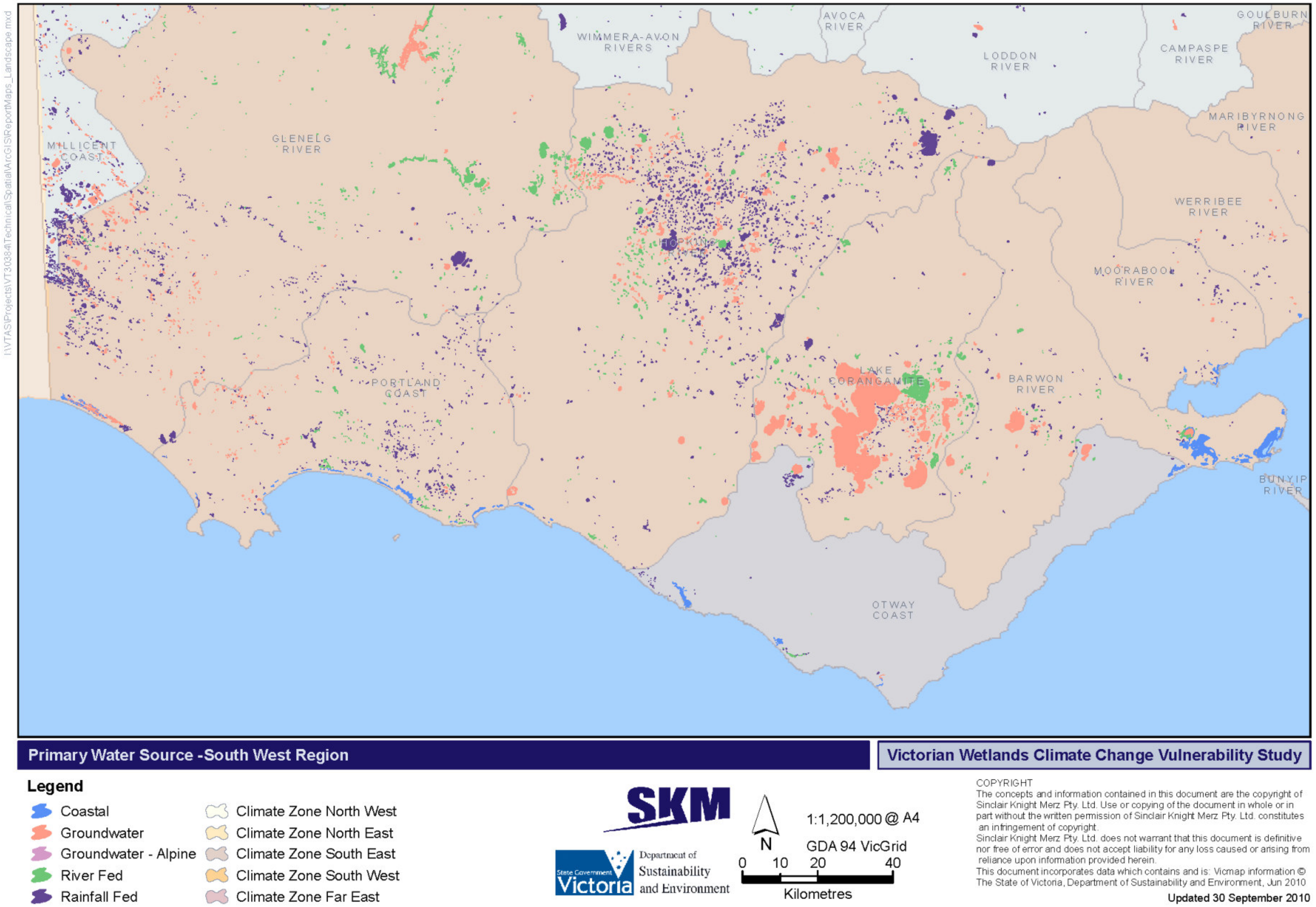


Figure 3.16 Wetlands in the south west region by primary water source

3.2.3.1 River fed wetlands

Flow frequency analysis was undertaken for the Merri River as an indicator of the effect climate change has on the frequency of river flows across the region that would inundate river fed wetlands. Table 3.9 and Figure 3.17 show that under natural (and current base case) conditions, flows that occur once every year will occur once every 1.5-2 years under medium climate change and once every 2.5-3 years under stepped climate change. Flows that currently occur once every 2 years will only occur once every 5 or 7 years under medium and stepped climate change respectively and flows that currently occur once every 5 years are predicted to occur only once every 20-25 years under climate change. Hence, wetlands that experience seasonal inundation once every 1 to 2 years will be inundated around once every 3 years under climate change predictions. While wetlands that experience inundation less frequently, say on average once every 5 years, may only be inundated once every 20-25 years under climate change.

Table 3.9 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared Average Recurrence Intervals under natural conditions for the Merri River.

Frequency of inundation	Flow (ML/day) equivalent to the natural historic climate ARI	Average recurrence interval – natural historic climate conditions	Equivalent Average Recurrence Interval – Base Case (current levels of demand historic climate)	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	2,040	1:1	1:1.1	1:1.7	1:2.6
Seasonal	2,400	1:2	1:2.1	1:4.8	1:7
	2,570	1:3	1:3.2	1:7.5	1:11
Intermittent	2,950	1:5	1:5.5	>1:25	>1:25
	3,200	1:10	1:11	>1:50	>1:50

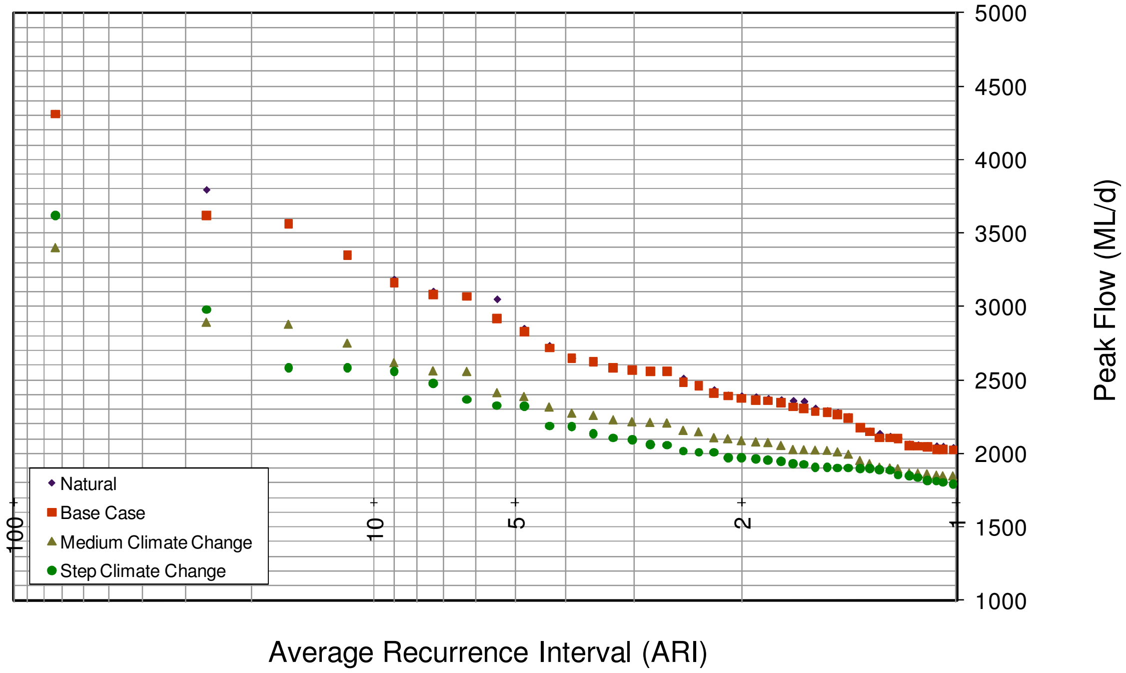
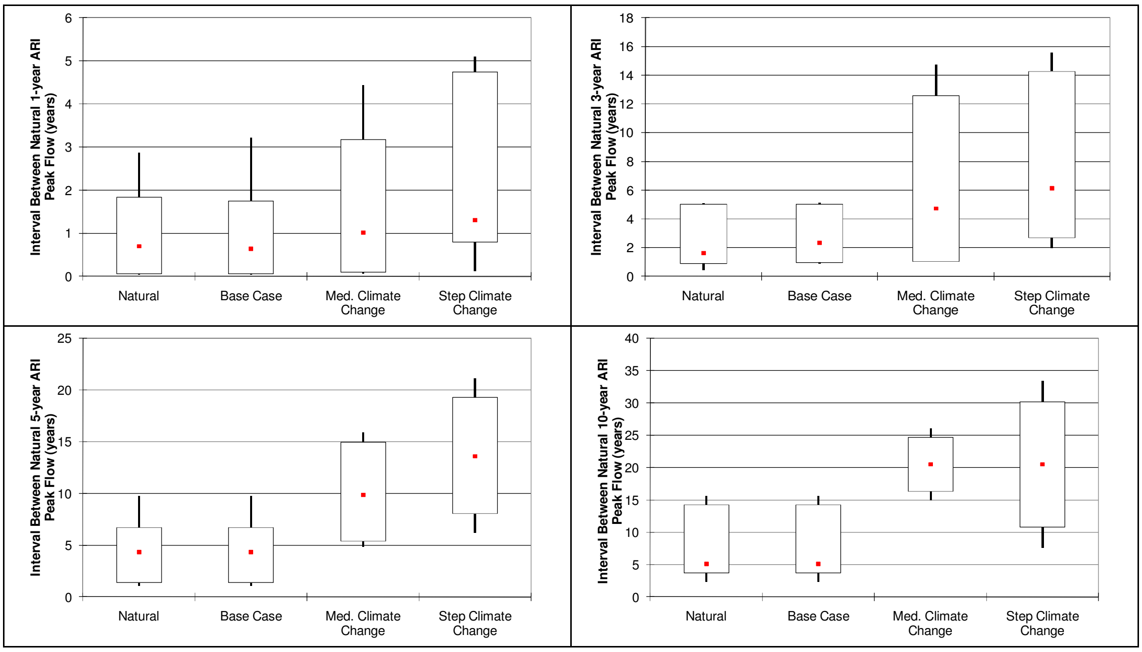


Figure 3.17 Average recurrence intervals for a range of flows in the Merri River under natural, current (Base Case) and medium and step climate change.

In addition to a reduction in the frequency of events that inundate seasonal wetlands, the interval between inundation events is predicted to increase. The interval between the 1:1 year event is not expected to change substantially as a result of climate change but the 90th%ile interval between this event (i.e. the interval during a dry period) is predicted to increase from 3 years to 5 years (Table 3.10). The median interval between the historical (natural) 1:3 year is expected to increase to from 1.6 years to 4.6 years under medium climate change and the 90th %ile interval is predicted to increase from around 5 years to 16 years (Figure 3.17).

Table 3.10 Median and 90th%ile interval (years) between events for range of ARI events under various scenarios for the Merri River.

ARI flow event	Percentile	Interval (years) between events for each scenario			
		Natural	BaseCase	Med CC	Step CC
1:1 year	Median	0.7	0.6	1.0	1.3
	90th%ile	2.9	3.2	4.4	5.1
1:3 year	Median	1.6	2.3	4.7	6.1
	90th%ile	5.1	5.1	14.7	15.6
1:5 year	Median	4.3	4.3	9.9	13.6
	90th%ile	9.8	9.8	15.9	21.2
1:10 year	Median	5.1	5.1	20.5	20.5
	90th%ile	15.6	15.6	26.0	33.4



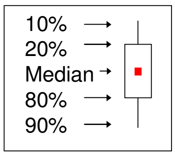


Figure 3.18 Box plot showing change in interval between events in the Merri River to demonstrate the effect of climate change on the interval between events that will inundate seasonal wetlands.

3.2.3.2 *Rainfall fed wetlands*

For rainfall fed wetlands in the south west the change in frequency of inundation events is less significant than for the river fed wetlands. Across the region annual rainfall is predicted to decline relatively uniformly, although catchments in the east, like the Werribee and Moorabool systems, are likely to experience a larger annual reduction in rainfall than other systems further west (Table 3.11).

Table 3.11 Percentage reduction in annual rainfall under dry and medium climate scenarios for 2030 and 2055

Basin	Rainfall gauge (#)	2030		2055	
		Dry	Med	Dry	Med
Maribyrnong		-7.9%	-4.2%	-16.7%	-8.8%
Werribee		-8.3%	-4.2%	-17.5%	-8.7%
Moorabool		-8.0%	-4.0%	-16.9%	-8.4%
Barwon		-6.8%	-3.6%	-14.3%	-7.4%
Lake Corangamite	Colac (90147)	-6.7%	-3.8%	-14.2%	-7.9%
Hopkins		-6.6%	-4.1%	-14.0%	-8.5%
Portland Coast		-6.0%	-3.8%	-12.6%	-7.9%
Glenelg		-6.7%	-4.2%	-14.2%	-8.7%

At Colac, which is located centrally within the region, rainfall is expected to decrease by up to 14% under climate change for the dry scenario by 2055. The median interval (years) between occurrence of the median recorded winter rainfall total (currently 238 mm over the winter period) is expected to increase from 1 to 2 years under medium and dry climate change scenarios between now and 2030. Although, the maximum interval between years when the median winter rainfall occurs remains similar to recorded (Figure 3.19). In other words, winter rainfall sufficient to inundate most rainfall fed wetlands will continue to occur in most years, but under the drier climate change scenarios there is likely to be an increase in the duration of some drier periods. However, by 2055, there is predicted to be a more substantial increase in the interval between median recorded winter rainfall, for the dry scenario. Under the dry scenario, wetlands that are currently inundated once every 1 to 2 years based on median winter rainfall may only be inundated once every 3-4 years.

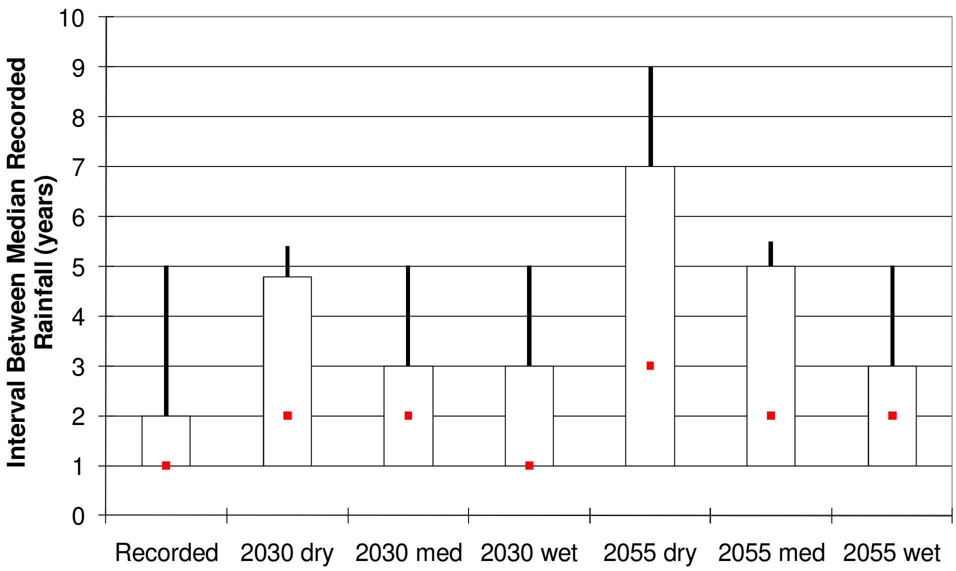


Figure3.19 Interval between median recorded winter rainfall (years) under climate change scenarios for Colac (Gauge 90147).

3.2.3.3 *Groundwater fed wetlands*

The majority of wetlands in the South West are associated with regional groundwater systems and are hence unlikely to be significantly affected by climate change induced reductions in rainfall, at least in the short to medium term (next 50 years). However, some significant wetlands are associated with local groundwater systems and hence are more vulnerable to climate change. For example, within the Cockajemmy Lakes region, a series of semi-permanent saline lakes near Willaura (eastern side of the Grampians), depth to groundwater data show levels to have varied significantly over the monitoring period (Figure 3.20). Depths have increased by over 1.5 m since the mid 1990s. This decline corresponds with reductions in rainfall over the same period (R^2=0.52 for the period 1995 to 2010), which suggests the groundwater system to be sensitive to decadal changes in climate. Shallow wetlands that rely on groundwater from local flow systems as their primary water source are therefore likely to be at risk from climate change due to associated changes in groundwater levels. These wetlands may continue to receive surface run off from local rainfall, but the duration of inundation is likely to decrease if they become disconnected from the groundwater system. They may also dry out more quickly, even if inundated by rainfall, due to high recharge flux rates once groundwater levels fall. Deeper wetlands may not be a significantly affected depending on the overall magnitude of the groundwater level decline.

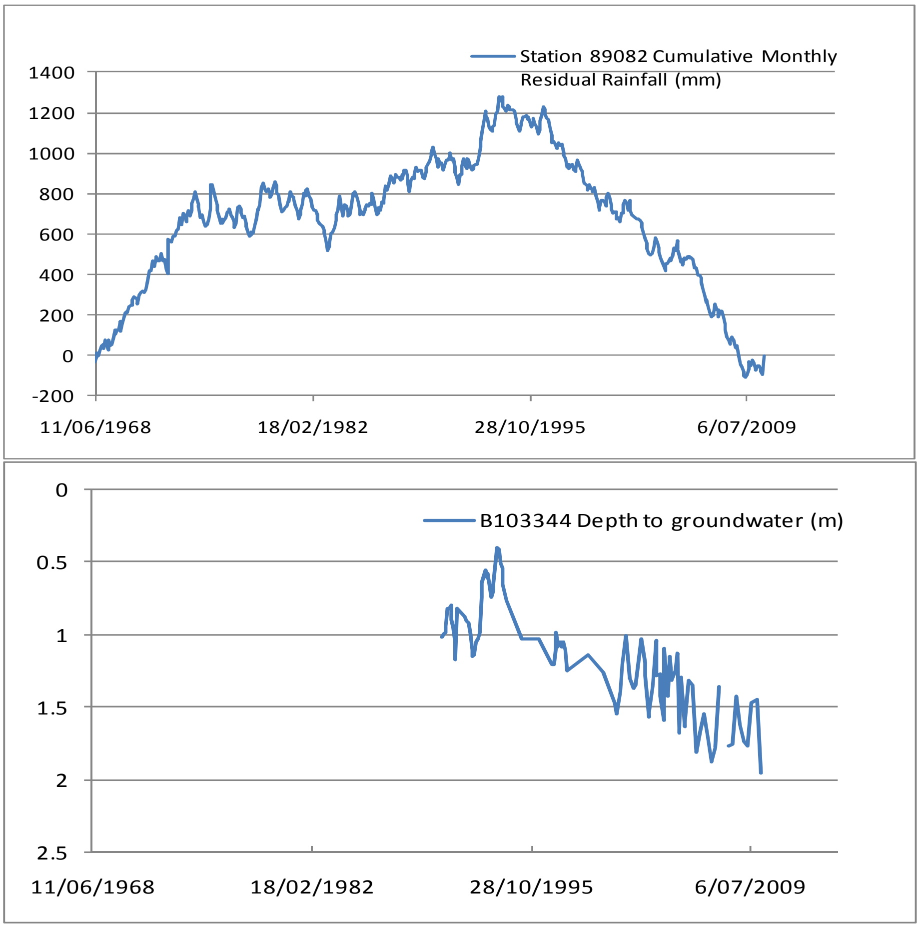
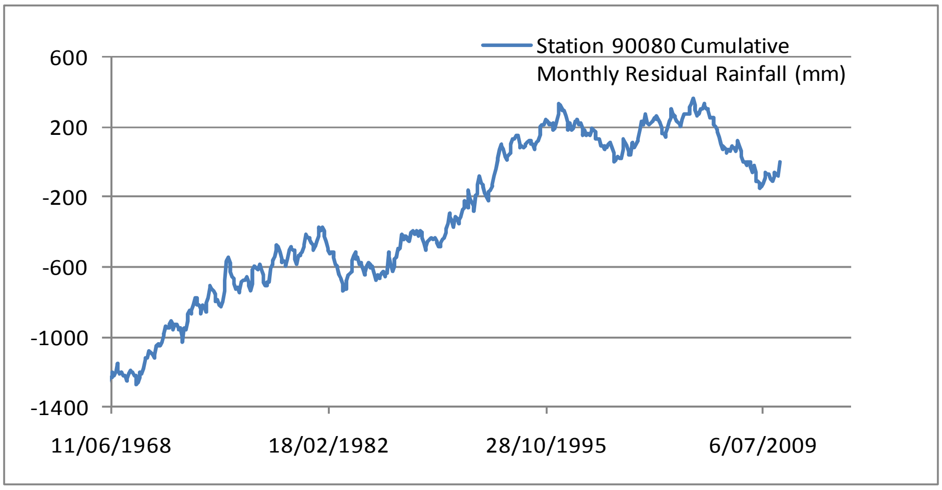


Figure 3.20 Relationship between rainfall and depth to nearby groundwater in the Willaura region. R^2=0.54 for correlation between residual rainfall and groundwater level from 1995 onwards, which represents the start of rainfall decline.

Further south, for permanent saline wetlands in the Corangamite area, depth to groundwater data shows level to have varied since the first reading in 1989 with groundwater levels at their lowest during last few months of the record (Figure 3.21). There is a general correspondence between the overall decline in depth to groundwater and that of rainfall since the mid 1990s (R2= 0.77 for the period 1997-2000 where rainfall and groundwater levels declined, R2=0.53 for the period 2001-2003 where rainfall and groundwater level increased and R2=0.83 for the period 2004-2009 where rainfall and groundwater level declined). Wetlands receiving primary inflows from groundwater are therefore likely to be sensitive to changes in climate also and at risk from further increases in depth to groundwater.



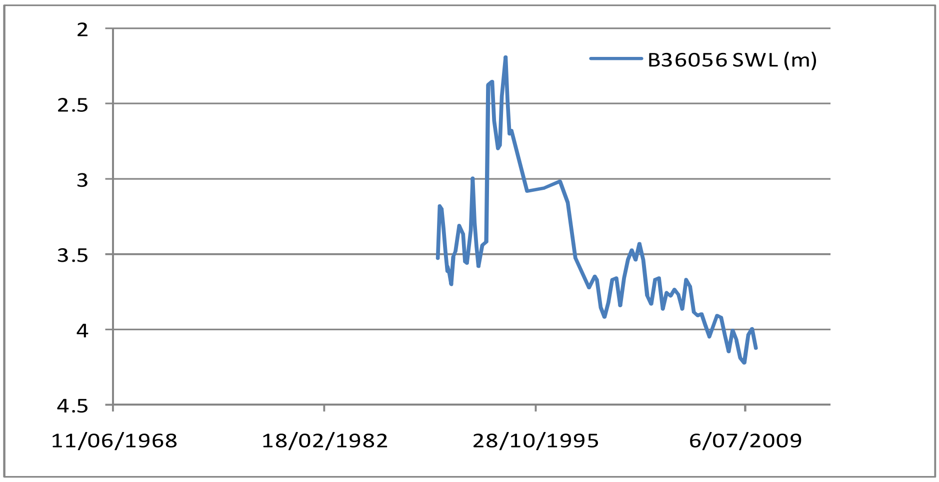
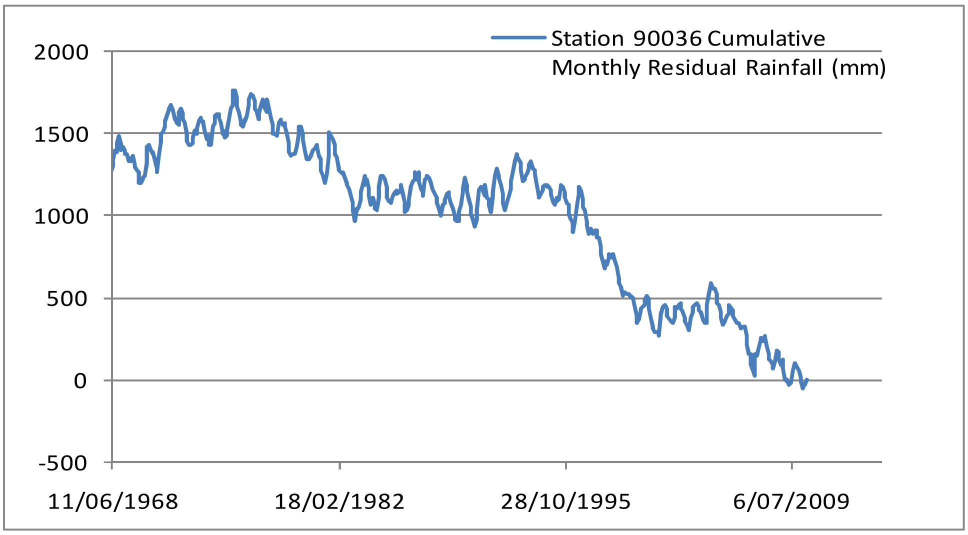


Figure 3.21 Relationship between rainfall at Warrion (Station 90080) north of Colac and depth to nearby groundwater. (R^2= 0.77 for the period 1997-2000 where rainfall and groundwater levels declined, R^2=0.53 for the period 2001-2003 where rainfall and groundwater level increased and R^2=0.83 for the period 2004-2009 where rainfall and groundwater level declined).

To the west of the region, west of Casterton, shallow freshwater marshes around Lake Mundi, appear at greater risk than the more saline systems because the magnitude of groundwater level decline is much greater (Figure 3.22). Here, groundwater levels have fallen by more than 4 meters in response to decadal decline in rainfall (R^2=0.89). Any shallow freshwater marshes reliant on groundwater in this region have probably already been affected by groundwater level decline. These wetlands are probably now more reliant on surface runoff for inundation events.



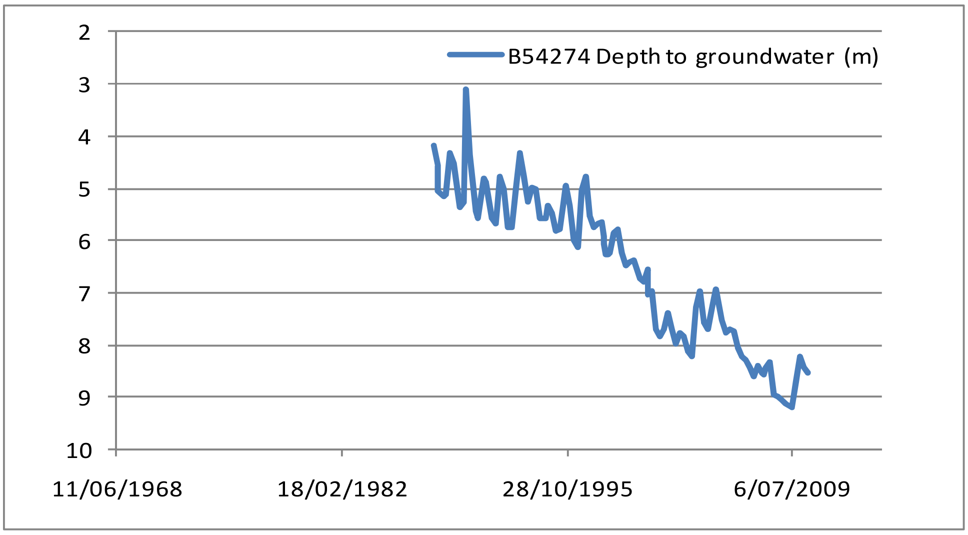


Figure 3.22 Relationship between rainfall and depth to nearby groundwater in the Lake Mundi region. R^2=0.89 for correlation between residual rainfall and groundwater level from 1988 onwards.

3.2.3.4 Coastal wetlands

The South west coast supports a significant area of coastal wetlands (19% of the state coastal wetlands by number but only 9% by area). Climate change is predicted to result in a 0.8 m rise in sea level. This rise in sea level will have varying impacts depending on topography of the coastline. In low relief areas, sea level rise is likely to result in the permanent inundation of wetlands that are currently tidal. These wetlands comprise mostly estuarine reed bed wetlands and swamp scrub, although mangroves exist in the eastern part of region around the Bellarine Peninsula and western shore of Port Phillip Bay. Wetlands that are currently intermittently inundated during spring tides and storm surges will become more frequently inundated. These wetlands are mostly coastal saltmarsh systems. A change in the frequency of sea water inundation will have dramatic effects on wetland vegetation types. Mangroves will advance into saltmarsh communities in the eastern part of the region and where topography allows, saltmarsh may be able to migrate inland. However, in many areas topography and also man-made features, such as seawalls, roads, drains and agricultural land will prevent the landward migration of coastal wetlands. Permanent coastal wetlands will persist, although their distribution will change, as too will tidal systems like estuarine reedbeds and swamp scrub wetlands. However, intermittent and episodic coastal wetlands (e.g., saltmarsh and estuarine (*Melaleuca*) scrubs) will be at most risk and are likely to diminish significantly in area.

3.2.3.5 Summary for south west region

In summary, for the south west region, river fed wetlands along the major river systems are likely to experience a small to moderate reduction in the frequency of inundation for wetlands that would have historically experienced seasonal inundation around once every one to three years. Stepped climate change will result in the greatest impact on river fed wetlands; increasing the interval between inundation events. This will result in a reduction in the diversity of aquatic and semi-aquatic plant species and an increase in terrestrial species that are tolerant of occasional flooding rather than those that are dependent on flooding. Seasonally inundated wetlands, which represent around 15% by number and 18% by area of all wetlands in the region, are at most risk.

For rain fed wetlands, under the worst case scenario, median winter rainfall is predicted to decline by around 17% by 2055 under the dry scenario in the east and by around 12% along the south west coast. This will result in an increase in the interval between inundation events from around once every 1 to 2 years to once every 3 years. However, other scenarios will result in a less dramatic decline in frequency of inundation and rain fed wetlands should continue to persist in the landscape.

Wetlands that access groundwater that is associated with regional scale groundwater flow systems are less likely to experience a change in the frequency of inundation compared to wetlands that are associated with local scale groundwater flow systems where a reduction in rainfall translates to a fall in groundwater levels below the bed level of most wetlands. Most groundwater fed wetlands appear located on regional groundwater systems. Permanent groundwater fed wetlands represent a large proportion of total wetland area in the region (~37%). Given most of these are associated with regional groundwater systems they are considered at low levels of risk from climate change, although they may still dry, or nearly dry, during extended dry periods, as has occurred over the past ten years.

Coastal wetlands that are currently above the mean high tide mark (intermittently and episodically inundated saltmarsh and estuarine wetlands) are at most risk from rising sea level. They will be invaded by mangrove (predominantly in the east of the region) and estuarine reed bed vegetation communities and may be constrained from landward migration due to topography and man-made barriers such as seawalls, roads and farms.

3.2.4 North East region

Figure 3.23 shows a map of wetlands in the north east region by primary water source. Figure 3.24 summarises the area and number of wetlands in the north east region by primary water source and frequency of inundation (more detail on percentage area and number can be found in Appendix B.4). Seasonal river fed wetlands (predominantly shallow freshwater marshes and freshwater meadows) make up the largest number and area of wetlands at 60% and 70% respectively of all wetlands in the region. Alpine wetlands are also significant, representing 27% by number but just 6.5% by area of all wetlands in the region.

As a proportion of the State, river fed wetlands in the north east region represent around 35% by number and area of all river fed wetlands in the state and alpine wetlands around 69% by number and 83% by area of all alpine wetlands in the state. In comparison with the west of the state, the north east region has relatively few wetlands (other than Alpine wetlands) where groundwater or rainfall has been identified as the primary water source, although there is a significant lack of groundwater data, to enable a definitive assessment of number of wetlands or potential impact. For example, many springs and soaks fed from shallow fractured-rock aquifers associated with the granitic geology of the Strathbogie and other ranges in the north east are likely to have been miss-classified or not even included in current data sets of the region.

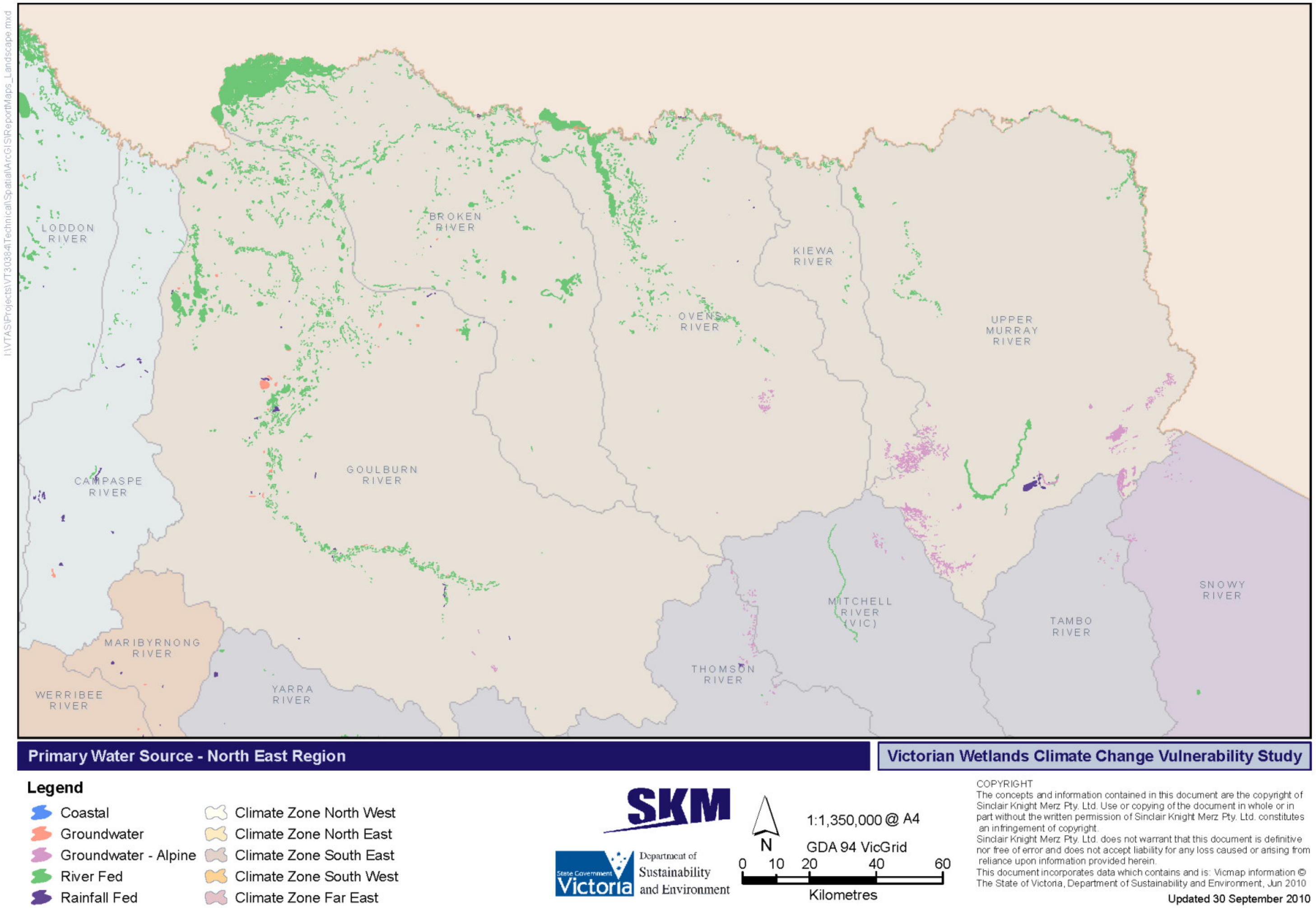


Figure 3.23 Wetlands in the north east region by primary water source

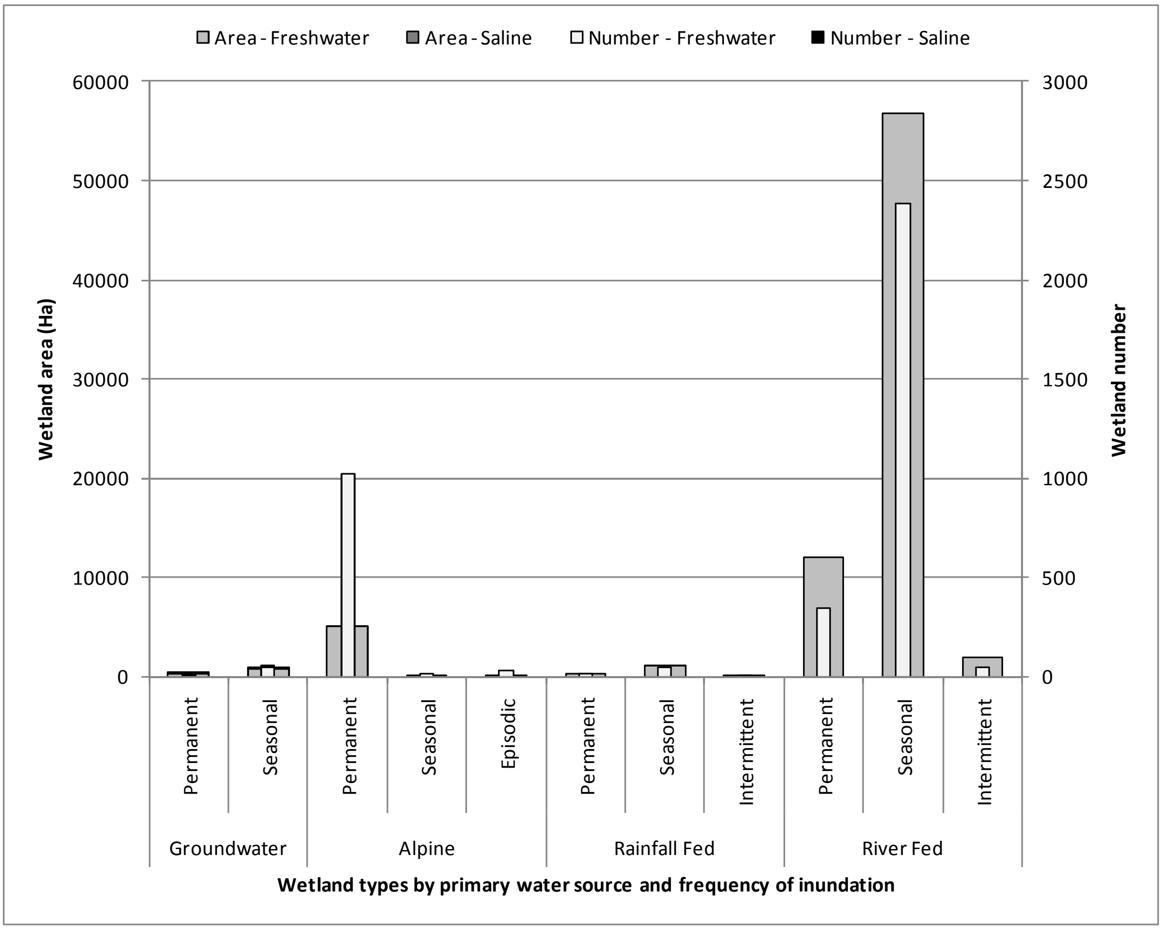


Figure 3.24 Area and number of wetland types by primary water source and current frequency of inundation in the North East region

3.2.4.1 River fed wetlands

Flow frequency analysis was undertaken for the Ovens and Goulburn Rivers as an indicator of the effect climate change has on the frequency of river flows across the region that would inundate river fed wetlands. Table 3.12 and Figure 3.25 for the Ovens River shows that under natural (and current base case) conditions, flows that occur once every year will occur once every ~1.8 years under medium climate change and once every 2.5 years under stepped climate change. Flows that currently occur once every 2 years will only occur once every 4 or 7 years under medium and stepped climate change respectively and flows that currently occur once every 5 years are predicted to occur only once every 14-35 years under climate change. Hence, wetlands that experience seasonal inundation once every 1 to 2 years will be inundated around once every 3 years under climate change predictions. While wetlands that experience inundation less frequently, say on average once every 5 years, may only be inundated once every 14-35 years under climate change.

Table 3.12 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared Average Recurrence Intervals under natural conditions for the Ovens River.

Frequency of inundation	Flow (ML/day) equivalent to the natural historic climate ARI	Average recurrence interval – natural historic climate conditions	Equivalent Average Recurrence Interval – Base Case (current levels of demand historic climate)	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	1,000	1:1	1:1	1:1.8	1:2.5
Seasonal	1,400	1:2	1:2	1:4	1:7
	1,790	1:3	1:3	1:8	1:14
Intermittent	2,000	1:5	1:5	1:14	1:35
	2,500	1:10)	1:10	1:35	1:80

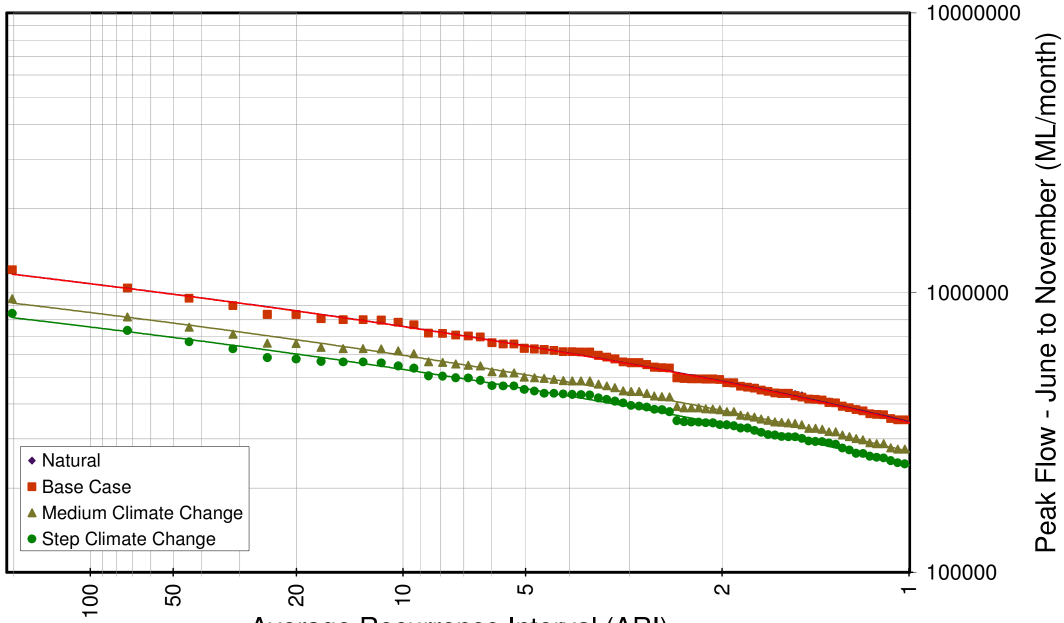


Figure 3.25 Average recurrence intervals for a range of flows in the Ovens River under natural, current (Base Case) and medium and step climate change.

As one moves west there is likely to be a larger reduction in the frequency of wetland inundation events. In contrast to the Ovens River, in the Goulburn River the natural 1:1 year event currently occurs once every 3 years as a result of river regulation and this is predicted to reduce further to once every 8 years under medium climate change and less frequently than once every 100 years under stepped climate change (Table 3.13 and Figure 3.26).

Table 3.13 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared Average Recurrence Intervals under natural conditions for the Goulburn River.

Frequency of inundation	Flow (ML/day) equivalent to the natural historic climate ARI	Average recurrence interval – natural historic climate conditions	Equivalent Average Recurrence Interval – Base Case (current levels of demand historic climate)	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	20,000	1:1	1:3	1:8	>1:100
Seasonal	30,000	1:2	1:7.5	1:30	>1:100
	36,600	1:3	1:14	1:80	>1:100
Intermittent	50,000	1:5	1:20	>1:100	>1:100
	56,600	1:10	1:40	>1:100	>1:100

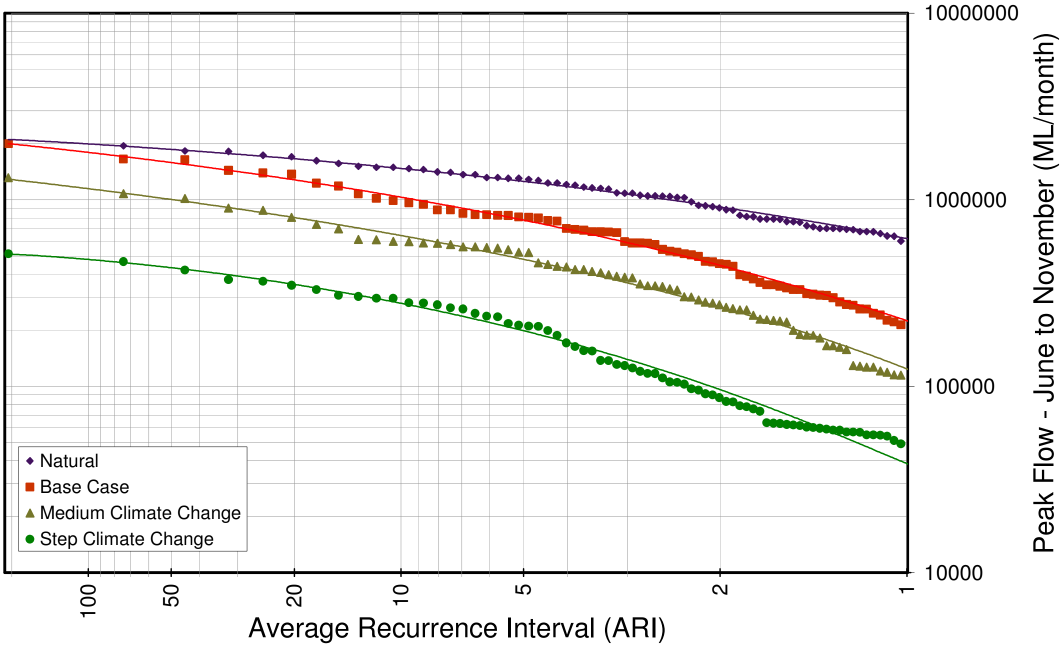


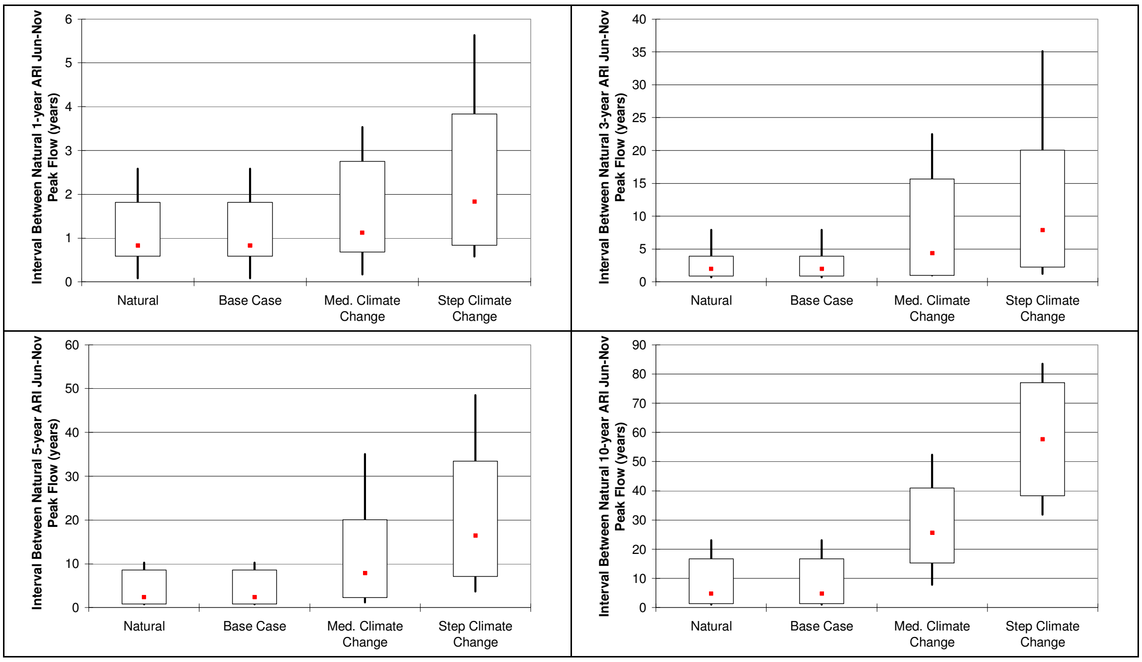
Figure 3.26 Average recurrence intervals for a range of flows in the Goulburn River under natural, current (Base Case) and medium and step climate change.

In addition to a reduction in the frequency of events that inundate seasonal wetlands as one moves westward across the region, the interval between inundation events is predicted to increase. In the Ovens Rivers the interval between the 1:1 year event is not expected to change substantially as a result of climate change but the 90th%ile interval between this event (i.e. the duration of the driest periods) is predicted to increase from 2.6 years to 5.6 years (Table 3.14). However, for the less frequent events, the interval between events is predicted to increase. For example, the median interval between the 1:5 year event is expected to increase from 2.4 years to 16 years under stepped climate change. The increase in interval between events is even more pronounced in the Goulburn River, even for the 1:1 year event. For wetlands that are located in regions with historically stable rainfall, like the North East, an increase in the duration of the dry phase (i.e. the 90th %ile) could be more significant than for wetlands located in regions with more variable rainfall and which are better adapted to a more variable regime.

Table 3.14 Median and 90th%ile interval (years) between events for range of ARI events under various scenarios for the Ovens and Goulburn Rivers.

ARI flow event	Percentile	Interval (years) between events for each scenario			
		Natural	BaseCase	Med CC	Step CC
Ovens River					
1:1 year	Median	0.8	0.8	1.1	1.8
	90th%ile	2.6	2.6	3.5	5.6
1:3 year	Median	2.0	2.0	4.4	7.9
	90th%ile	7.9	7.9	22.5	35.1
1:5 year	Median	2.4	2.4	7.9	16.4
	90th%ile	10.3	10.3	35.1	48.5
1:10 year	Median	4.8	4.8	25.6	57.6
	90th%ile	23.0	23.0	52.3	83.5
Goulburn River					
1:1 year	Median	0.8	1.7	4.7	117
	90th%ile	2.7	8.9	17.0	117
1:3 year	Median	2.0	12.0	58.3	117
	90th%ile	8.7	25.6	83.5	117
1:5 year	Median	4.8	19.1	117	117
	90th%ile	16.4	33.8	117	117
1:10 year	Median	12.0	31.9	117	117
	90th%ile	25.8	38.3	117	117

Figure 3.27 and Figure 3.28 compare the differences between the Ovens and Goulburn Rivers in the range over which the interval between events is predicted to increase under climate change scenarios.



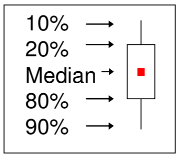
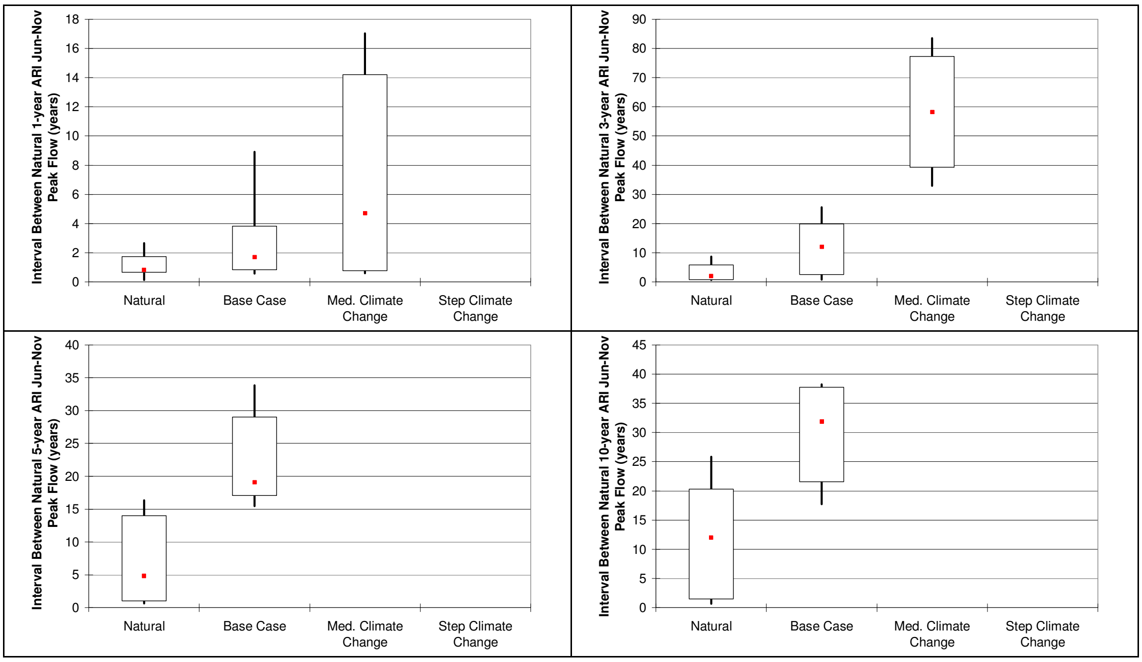


Figure 3.27 Box plots showing change in interval between inundation events for the Ovens River.



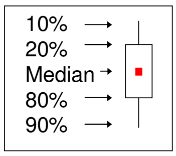


Figure 3.28 Box plots showing change in interval between inundation events for the Goulburn River.

3.2.4.2 Rainfall fed wetlands

For rainfall fed wetlands in the north east the change in frequency of inundation events is less significant than for the river fed wetlands. Across the region annual rainfall is predicted to decline from east to west with the greatest decline of around 14% in the Goulburn catchment by 2055 under the dry scenario (Table 3.15).

Table 3.15 Percentage reduction in annual rainfall under dry medium and wet climate scenarios for 2030 and 2055

		2030		2055	
Basin	**Rainfall gauge (#)**	**Dry**	**Med**	**Dry**	**Med**
Upper Murray		-4.6%	-2.7%	-9.8%	-5.6%
Kiewa	Rocky Valley (83043)	-5.3%	-3.1%	-11.2%	-6.5%
Ovens		-5.9%	-3.5%	-12.6%	-7.2%
Broken		-6.3%	-3.8%	-13.3%	-7.9%
Goulburn	Mooroopna (81034)	-6.7%	-4.0%	-14.2%	-8.3%

At Rocky Valley, which is located in the alpine areas in the upper reaches of the Kiewa catchment, rainfall is expected to decrease by up to 11% under the dry scenario by 2055. The median interval (years) between occurrence of the median recorded winter rainfall total (currently 892 mm over the winter period) is expected to increase from 1 to 2 years under dry climate change scenarios between now and 2030. The maximum interval between years when the median winter rainfall occurs remains similar to recorded but is likely to increase under the dry scenario, especially by 2055 (Figure 3.29).

In the lower Goulburn catchment, around Shepparton, rainfall is predicted to decline by up to 14% under the dry scenario by 2055. The median interval between occurrences of the median recorded winter rainfall total (currently 145 mm) is not predicted to change, but under the dry scenario the maximum interval between the median winter rainfall will increase substantially by 2055 (Figure 3.30).

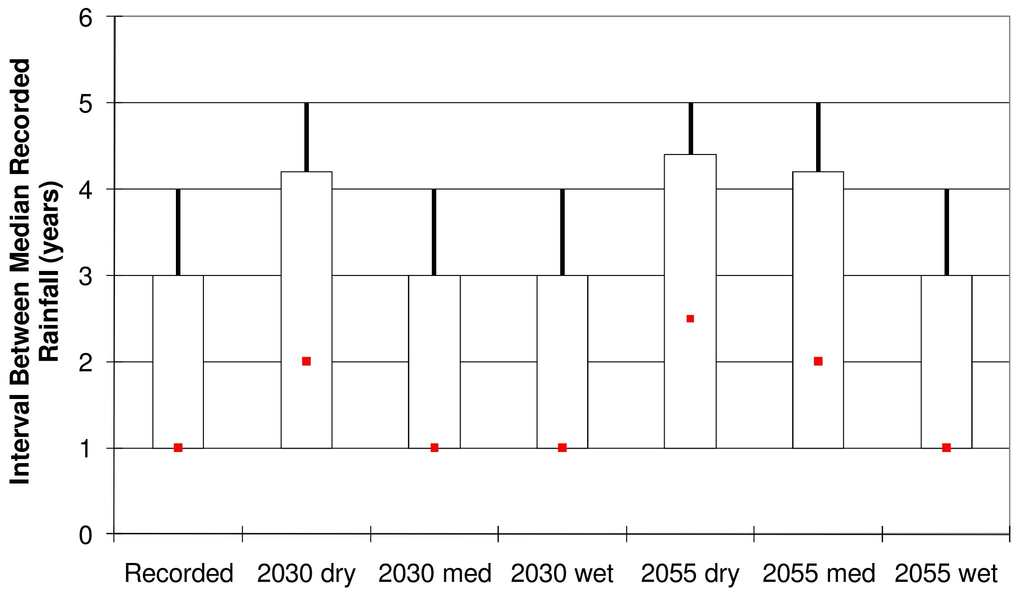


Figure 3.29 Interval between median recorded winter rainfall (years) under climate change scenarios for Rocky Valley (Gauge 83043).

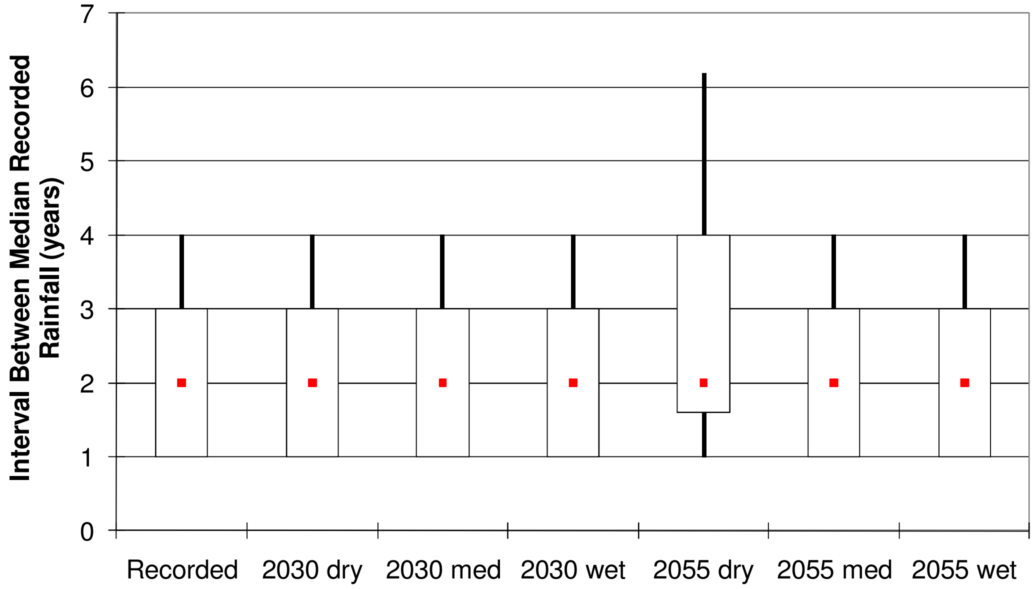


Figure 3.30 Interval between median recorded winter rainfall (years) under climate change scenarios for Mooroopna (Gauge 81034).

3.2.4.3 Groundwater fed and alpine wetlands

There is very limited groundwater data for the north east region and relative few groundwater wetlands compared with other regions. However, studies that have been undertaken support the thesis that wetlands connected to local groundwater flow systems are most vulnerable to climate change induced drying. In particular, Stewardson *et al*. (2009) show that for spring soaks and bogs in the Strathbogie Ranges, reduced rainfall over the last decade has been a significant driver of reduced spring discharge to these wetlands via a reduction in recharge to shallow fractured-rock aquifers that feed spring soaks on the flanks of the granitic ranges. This is an area that requires further investigation more broadly across the region, and indeed the state.

The impacts of climate change on alpine wetlands are discussed more generally in Section 3.2,7.

3.2.4.4 Summary for north east region

In summary, for the north east region, river fed wetlands along rivers in the east (e.g. the Ovens River) are likely to experience a small reduction in the frequency of inundation for wetlands that would have historically experienced seasonal inundation around once every one to three years. However, for rivers further west there is a more significant decrease in the interval between inundation events under climate change. Stepped climate change will result in the greatest impact on river fed wetlands; increasing the interval between inundation events.

As in other regions, seasonal wetlands are the most numerous wetlands in the region (60% by number and 70% by area). While the shift in water regime various across the region from east to west, a large proportion of these seasonal wetlands are associated with the floodplain of the Goulburn River and are likely to shift towards a more intermittent regime, which currently represents only a very small proportion of wetlands in the region.

For rain fed wetlands, under the worst case scenario, median winter rainfall is predicted to decline by around 14% by 2055 under the dry scenario in the west and by around 10% in the east. This will result in an increase in the interval between inundation events from around once every 1 year to once every 2-3 years. However, other scenarios will result in a less dramatic decline in frequency of inundation and rain fed wetlands should continue to persist in the landscape.

3.2.5 South East and Otway Coast region

Figure 3.31 summarises the number and area of wetlands in the south east region (including the Otway Coast) by primary water source and frequency of inundation (Appendix B.5 provides more details on area, numbers and percentages). Figure 3.32 shows a map of wetlands in south east region by primary water source (see Figure 3.15 for Otway coast wetlands). Rainfall fed wetlands make up the largest number of wetlands at 47% of all wetlands in the region but on 4.8% by area. River fed wetlands represent 30% by number and just 5.8% by area. Coastal wetlands represent 10% of wetlands by number in the region but 73% by area in the region and 81% by area for the whole state. Alpine wetlands within the region represent 25% by number and 16% by area of all the states alpine wetlands. There are relatively few groundwater fed wetlands by area or number.

Of all freshwater wetlands, seasonal wetlands are the most numerous but permanently inundated wetlands cover the greatest area. For coastal wetlands, permanently inundated wetlands cover the greatest area, followed by intermittently inundated coastal saltmarsh.

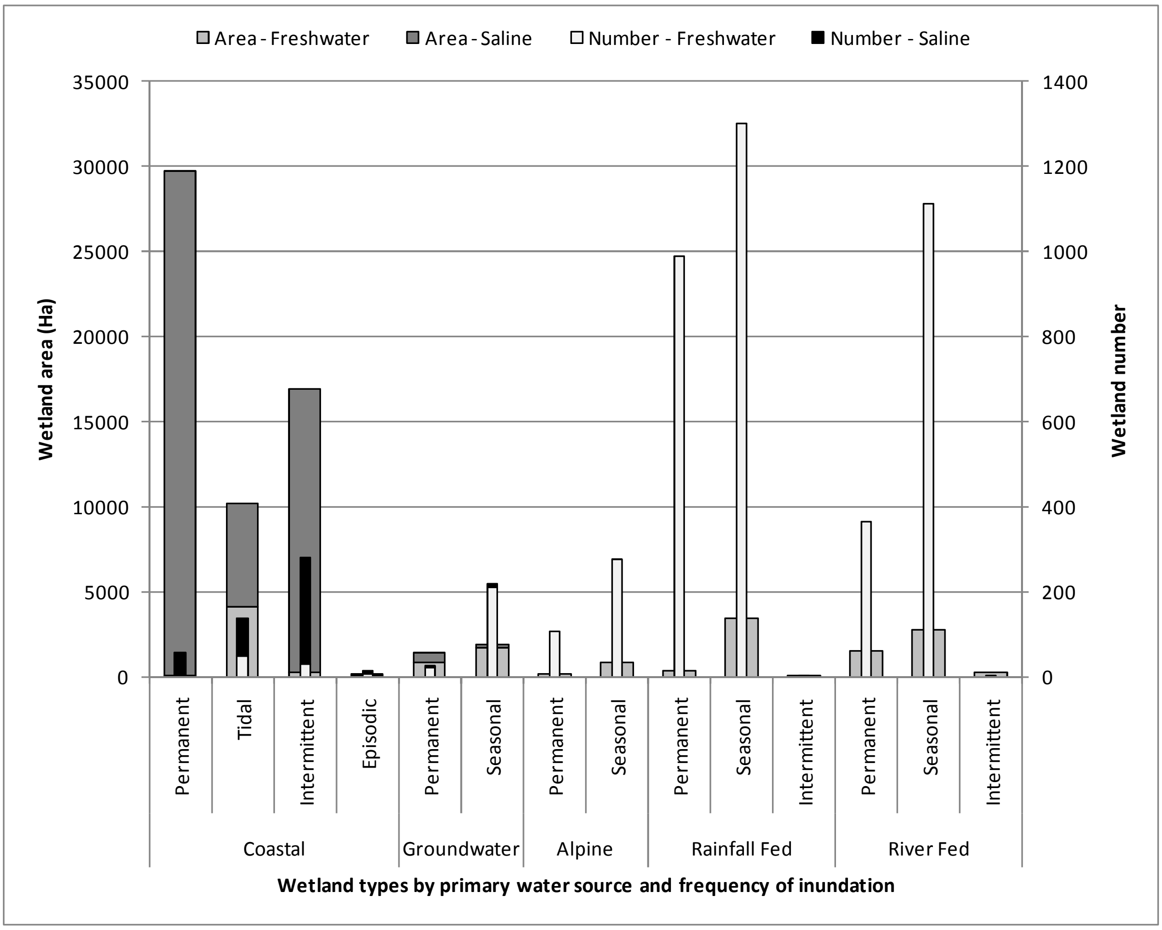


Figure 3.31 Area and number of wetland types by primary water source and current frequency of inundation for the South East and Otway coast region.

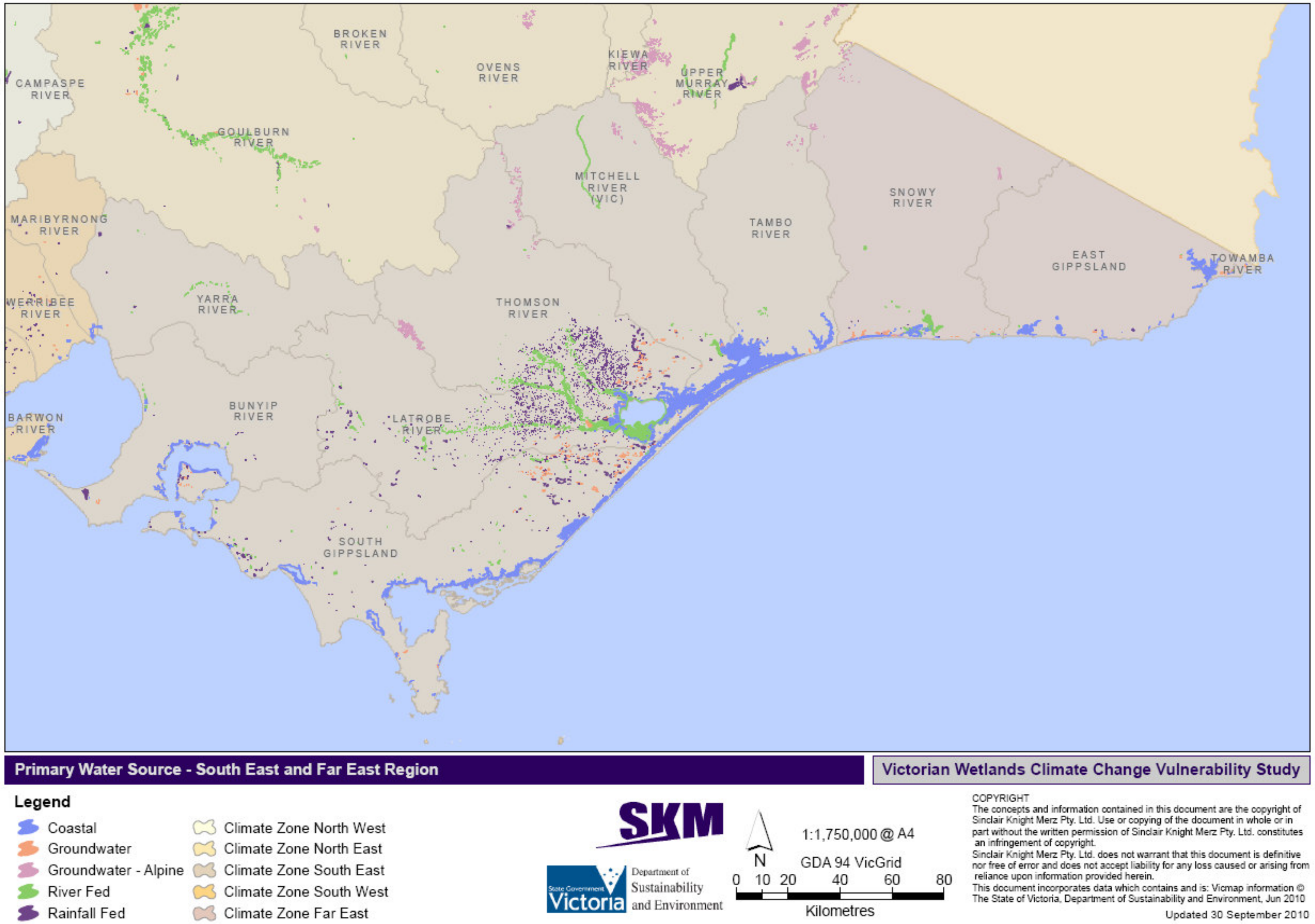


Figure 3.32 Wetlands in the south east and far east regions by primary water source

3.2.5.1 River fed wetlands

Flow frequency analysis was undertaken for the Latrobe River as an indicator of the effect climate change has on the frequency of river flows across the region that would inundate river fed wetlands (note, suitable flow data was not available for a more detailed assessment of other rivers within the region). Table 3.16 and Figure 3.33 for the Latrobe River shows that under natural (and current base case) conditions, flows that occur once every year will occur once every 2 years under medium climate change and once every 6 years under stepped climate change. Flows that currently occur once every 2 years will only occur once every 4 under medium but only once every 20 years under stepped climate change. Less frequent flows are predicted to be significantly impacted with climate change resulting in flows currently equivalent to 1:5 and 1:10 year flows occurring less frequently than every 50 years.

The median interval between the 1:1 year event is predicted to increase to 6 years under stepped climate change and the 90th%ile interval between this event (i.e. the interval during a dry periods) is predicted to increase from 3 years to 15 years (Table 3.17 and Figure 3.34). For the less frequent events, the increase in interval between events is predicted to be even greater. For example, the median interval between the 1:5 year event is expected to increase from 2.4 years to >50 years under stepped climate change.

Table 3.16 Comparison of Average Recurrence Intervals (years) under modelled scenarios compared to Average Recurrence Intervals under natural conditions for the Latrobe River.

Frequency of inundation	Flow (ML/day) equivalent to the natural historic climate ARI	Average recurrence interval – natural historic climate conditions (approximate flow ML/day)	Equivalent Average Recurrence Interval – Base Case (current levels of demand historic climate)	Equivalent Average Recurrence Interval – current levels of demand medium climate change	Equivalent Average Recurrence Interval – current levels of demand step climate change
Permanent	1,480	1:1	1:1	1:2	1:6
Seasonal	5,500	1:2	1:2	1:4	1:20
	6,600	1:3	1:4	1:8	>1:50
Intermittent	8,200	1:5	1:7	1:20	>1:50
	9,600	1:10	1:15	>1:50	>1:50

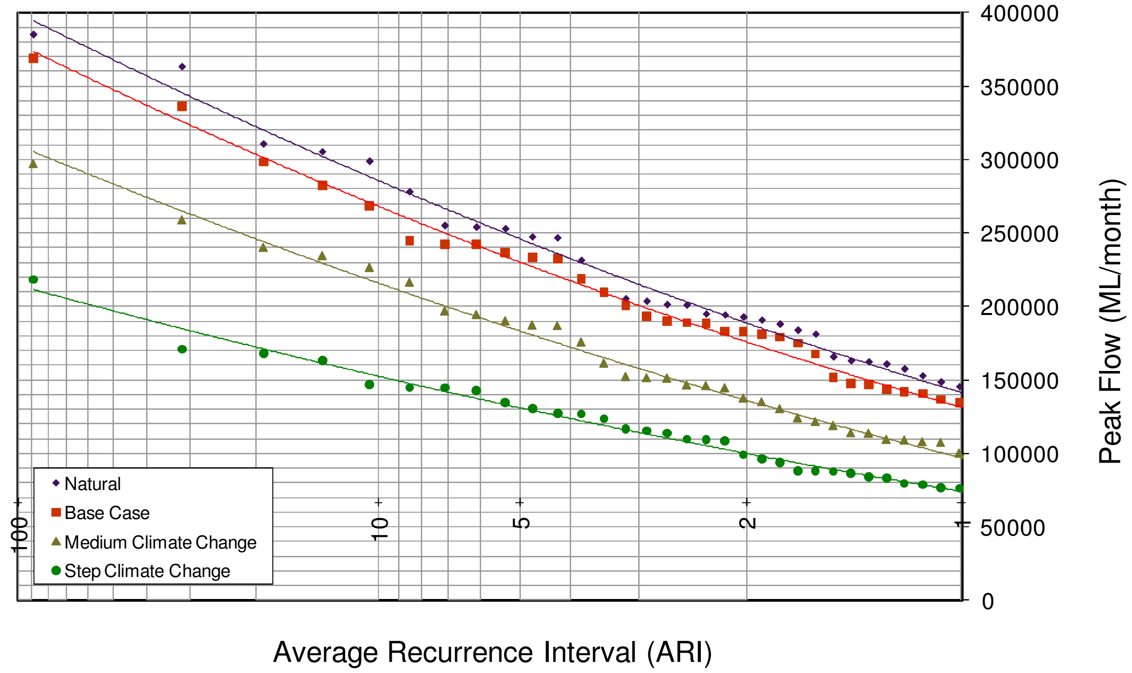
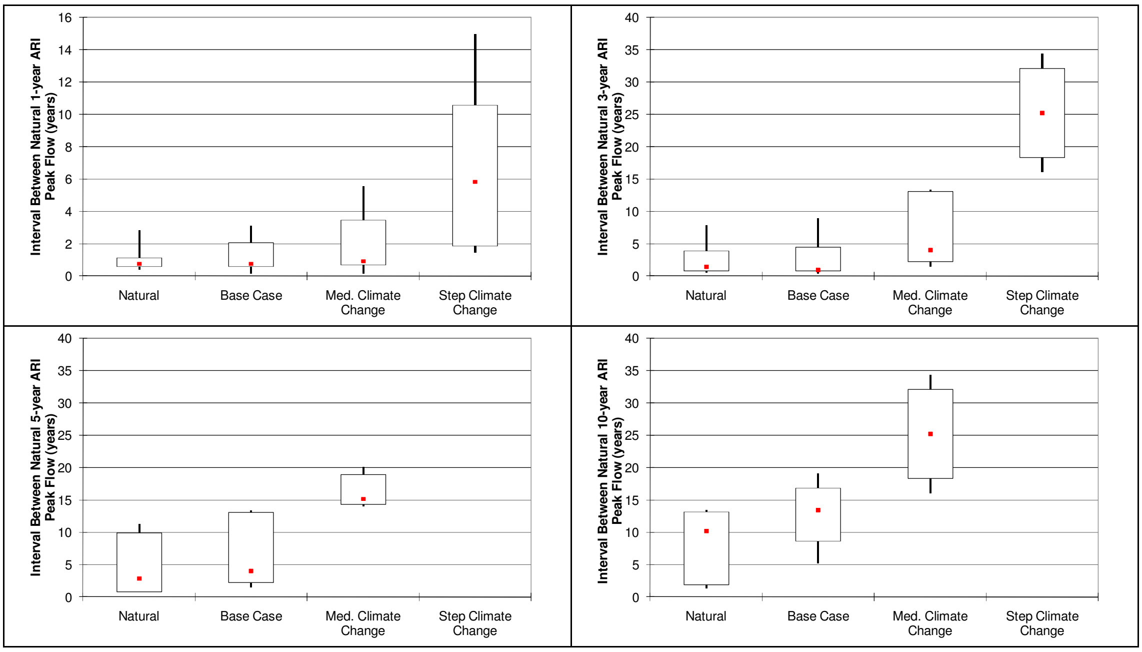


Figure 3.33 Average recurrence intervals for a range of flows in the Latrobe River under natural, current (Base Case) and medium and step climate change.

Table 3.17 Median and 90th%ile interval (years) between events for range of ARI events under various scenarios for the Latrobe River.

ARI flow event	Percentile	Interval (years) between events for each scenario			
		Natural	BaseCase	Med CC	Step CC
1:1 year	Median	0.8	0.8	0.9	5.8
	90th%ile	2.8	3.1	5.5	15.0
1:3 year	Median	1.4	0.9	4.0	25.2
	90th%ile	7.9	9.0	13.4	34.4
1:5 year	Median	2.8	4.0	15.2	
	90th%ile	11.3	13.4	20.2	
1:10 year	Median	10.2	13.5	25.2	
	90th%ile	13.5	19.1	34.4	



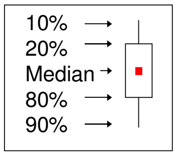


Figure 3.34 Box plots showing change in interval between inundation events for the Latrobe River.

3.2.5.2 Rainfall fed wetlands

For rainfall fed wetlands in the south east the change in frequency of inundation events is less significant than for the river fed wetlands. Rainfall is predicted to decline from east to west by up to 14% under the dry scenario by 2055 in the west of the region but only by around 7% in the south (Table 3.18).

Table 3.18 Percentage reduction in annual rainfall under dry medium and wet climate scenarios for 2030 and 2055

		2030		2055	
Basin	**Rainfall gauge (#)**	**Dry**	**Med**	**Dry**	**Med**
Mitchell	Lindenow (85050)	-4.8%	-2.9%	-10.1%	-6.1%
Thomson		-5.3%	-3.1%	-11.3%	-6.5%
Latrobe		-5.1%	-2.7%	-10.7%	-5.6%
South Gippsland		-3.5%	-2.0%	-7.3%	-4.2%
Bunyip	Labertouch (85046	-5.1%	-3.0%	-10.7%	-6.3%
Yarra	Yan Yean (86131)	-6.6%	-3.8%	-13.9%	-7.9%
Otway Coast		-4.9%	-3.0%	-10.4%	-6.4%

At Labertouch, which is located in the central parts of the region, rainfall is expected to decrease between 1.3% and 11% under climate change. The median interval (years) between occurrence of the median recorded winter rainfall total (currently 223 mm over the winter period) is not predicted to change markedly, but the maximum interval between years when the median winter rainfall occurs is likely to increase under the dry scenario, especially by 2055 (Figure 3.35).

In the east of the region, around Bairnsdale (Lindenow), rainfall is predicted to also decline between 1 and 14%. The median interval between occurrences of the median recorded winter rainfall total (currently 140 mm) is predicted to increase from 1 to 2 years under the medium and dry scenarios (Figure 3.36).

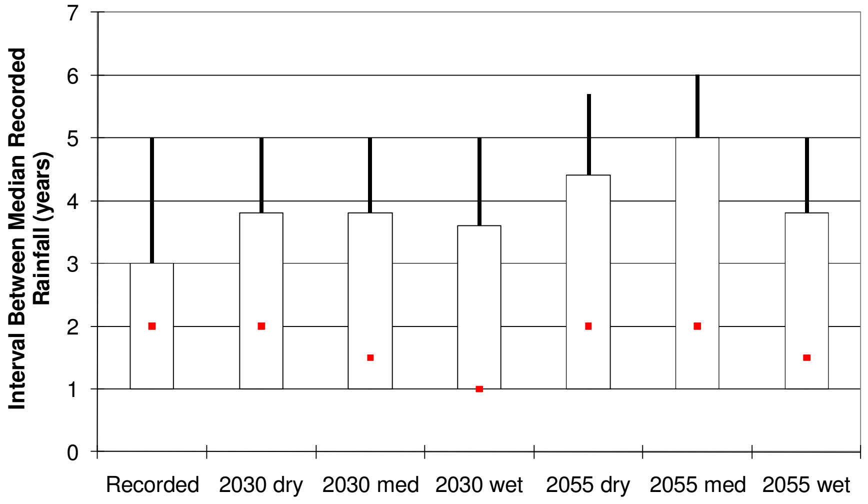


Figure 3.35 Interval between median recorded winter rainfall (years) under climate change scenarios for Labertouch (Gauge 85046).

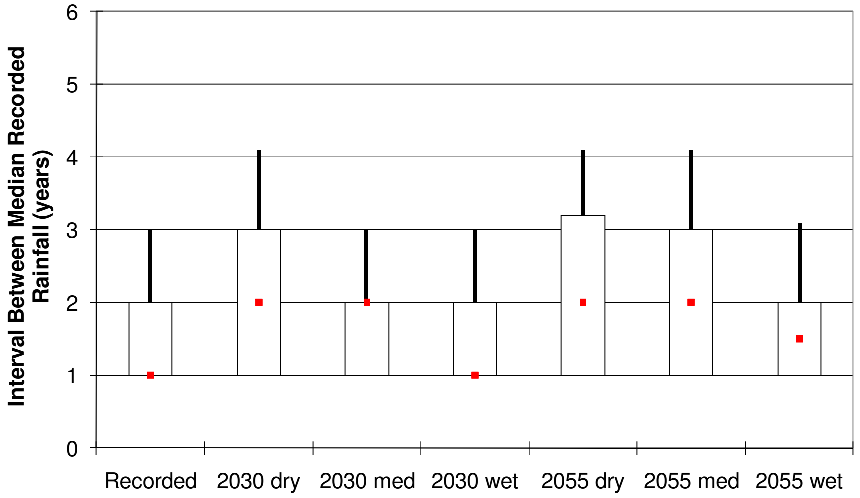
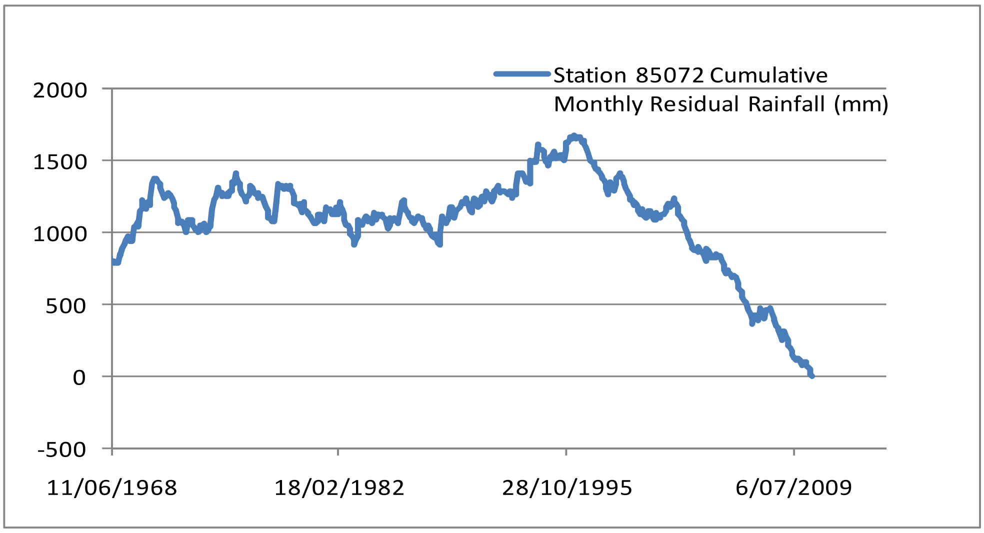


Figure 3.36 Interval between median recorded winter rainfall (years) under climate change scenarios for Lindenow (Gauge 85050).

3.2.5.3 Groundwater fed and alpine wetlands

Within the Sale region, available depth to groundwater data show levels to have been at within 0.5 and 1 m from the surface in the early 1990s, with a general decline since that time of up to 3 m. This trend is generally consistent with that of rainfall over the same period (R^2=0.64), suggesting the system is sensitive to decadal changes in rainfall (Figure 3.37). Wetlands with groundwater as their primary source of water are therefore also likely to be impacted by climate change and at risk from further reductions in groundwater levels.



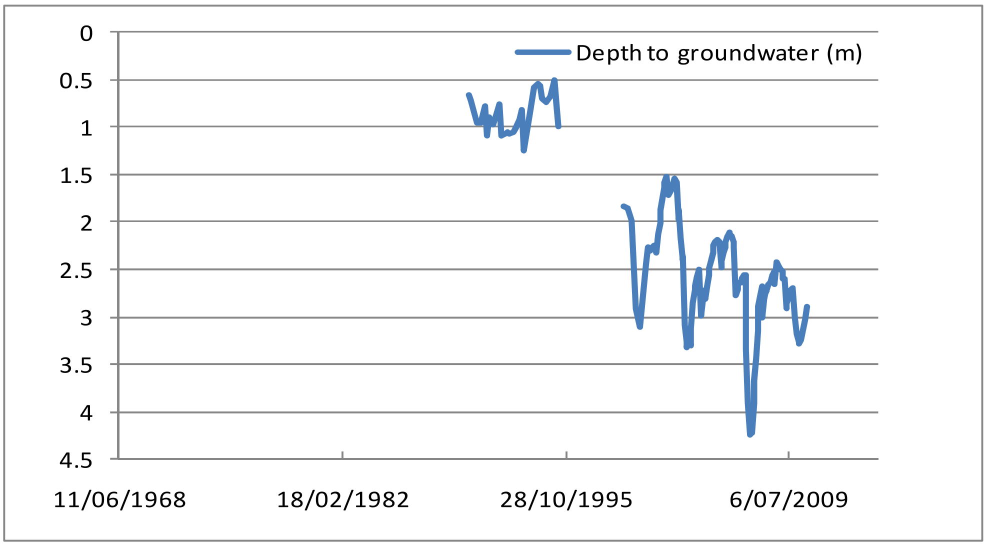


Figure 3.37 Relationship between rainfall and depth to nearby groundwater around Sale. R^2=0.64 for correlation between residual rainfall and groundwater level from 1989 onwards.

The impacts of climate change on alpine wetlands are discussed more generally in Section 0.

3.2.5.4 Coastal wetlands

The Gippsland coast supports a significant area of coastal wetlands (67% of the state coastal wetlands by number and 81% by area). Climate change is predicted to result in a 0.8 m rise in sea level. This rise in sea level will have varying impacts depending on topography of the coastline. In low relief areas, sea level rise is likely to result in the permanent inundation of wetlands that are currently tidal. These wetlands comprise mostly mangrove and estuarine reed bed wetlands. Wetlands that are currently intermittently inundated during spring tides and storm surges will become more frequently inundated. These wetlands are mostly coastal saltmarsh systems. A change in the frequency of sea water inundation will have dramatic effects on wetland vegetation types. Mangroves will advance into saltmarsh communities and where topography allows, saltmarsh may be able to migrate inland. However, in many areas topography and also man-made features, such as seawalls, roads, drains and agricultural land will prevent the landward migration of coastal wetlands. Permanent coastal wetlands will persist, although their distribution will change, as too will tidal systems like mangrove wetlands. However, intermittent and episodic coastal wetlands (e.g., saltmarsh and estuarine (*Melaleuca*) scrubs) will be at most risk and are likely to diminish significantly in area.

3.2.5.5 Summary for south east region

In summary, for the south east and Otways region, river fed wetlands along the major river systems are likely to experience a small to moderate reduction in the frequency of inundation for wetlands that would have historically experienced seasonal inundation around once every one to three years. Stepped climate change will result in the greatest impact on river fed wetlands; increasing the interval between inundation events and affecting around 22% of wetlands by number but only 3.5% by area. This will result in a reduction in the diversity of aquatic and semi-aquatic plant species and an increase in terrestrial species that are tolerant of occasional flooding rather than those that are dependent on flooding.

For rain fed wetlands, under the worst case scenario, median winter rainfall is predicted to decline by around 14% by 2055 under the dry scenario in the west and by around 7% along the southern coast. This will result in an increase in the interval between inundation events from around once every 1 year to once every 2 years. However, other scenarios will result in a less dramatic decline in frequency of inundation and rain fed wetlands should continue to persist in the landscape.

Wetlands that access groundwater that is associated with regional scale groundwater flow systems are less likely to experience a change in the frequency of inundation compared to wetlands that are associated with local scale groundwater flow systems where a reduction in rainfall translates to a fall in groundwater levels below the bed level of most wetlands.

Coastal wetlands that are currently above the mean high tide mark (intermittently and episodically inundated coastal saltmarsh and estuarine wetlands) are at most risk from rising sea level. They will be invaded by mangrove and estuarine reed bed vegetation communities and may be constrained from landward migration due to topography and man-made barriers such as seawalls, roads and farms.

3.2.6 Far east region

Wetlands associated with the far east region can be seen on Figure 3.32. Figure 3.38 summarises the area and number of wetlands in the far east region by primary water source and frequency of inundation (Appendix B.6 provides details on number, area and percentages). Alpine wetlands make up the largest number of wetlands (37%) but less than 1% by area. Coastal wetlands represent 32% of the wetlands in the region by number and 60% of wetlands by area and around 10% of all the coastal wetlands in the State. Most of these are permanent wetlands. River fed wetlands represent around 10% of wetlands by number and area. There is relatively few rainfall or groundwater fed wetlands by area or number. As a percentage of the State overall, wetlands in the far east represent just 1.2% by number and 2.2% by area.

The far east is relatively undeveloped compared with the central and western parts of Victoria. Rivers in the far east are unregulated and there is no modelling of the change in frequency of river flow with climate change. Furthermore, there are few groundwater bores where trends in depth to water table can be tracked.

Rainfall in the far east is predicted to decline from east to west by up to 8.6% under the dry scenario by 2055 in the west of the region but only by around 3.7% in the east (Table 3.19). At Point Hicks, in the east, rainfall is expected to decrease by less than 4% under the driest scenario. The median interval (years) between occurrence of the median recorded winter rainfall total (currently 245 mm over the winter period) is not predicted to change under any scenario (Figure 3.39).

Table 3.19 Percentage reduction in annual rainfall under dry medium and wet climate scenarios for 2030 and 2055

Basin	Rainfall gauge (#)	2030		2055	
		Dry	Med	Dry	Med
East Gippsland	Point Hicks	-1.8%	-0.1%	-3.7%	-0.3%
Snowy River		-3.0%	-1.2%	-6.4%	-2.5%
Tambo River		-4.1%	-2.1%	-8.6%	-4.4%

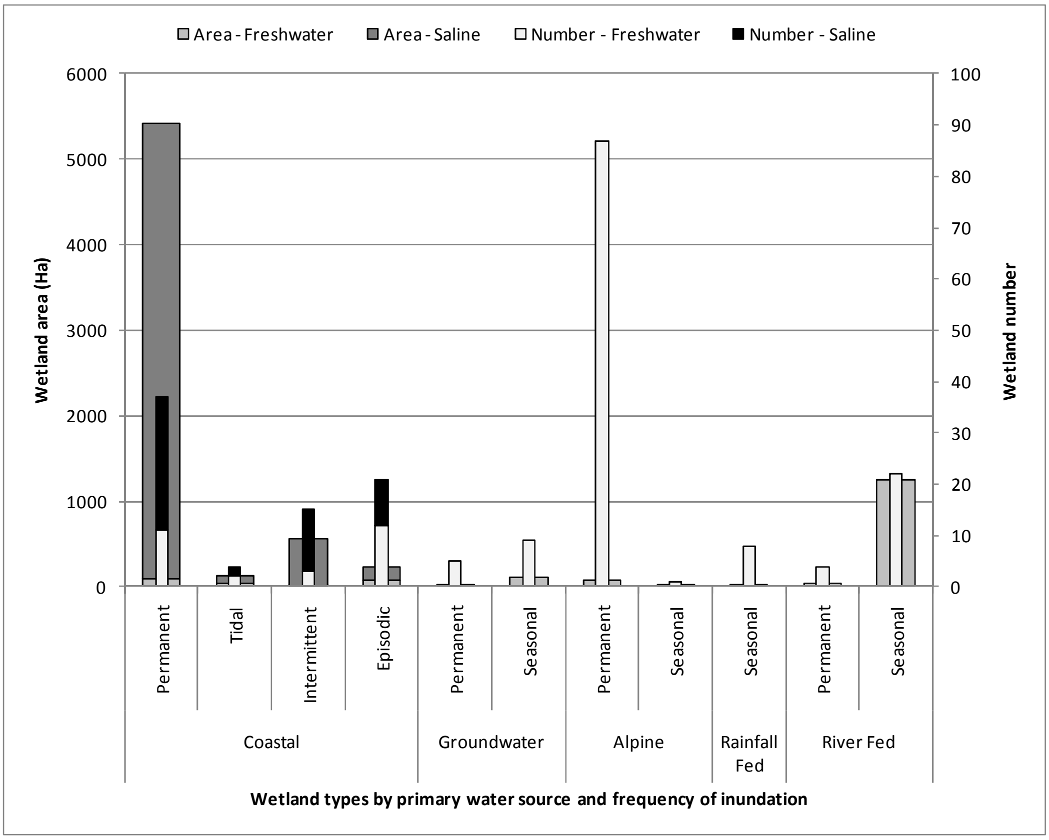


Figure 3.38 Area and number of wetland types by primary water source and current frequency of inundation

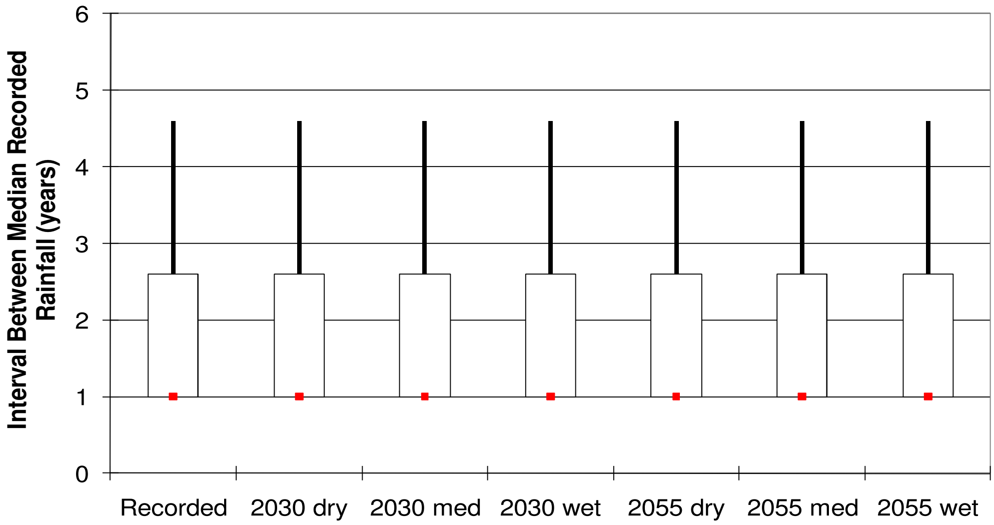


Figure 3.39 Interval between median recorded winter rainfall (years) under climate change scenarios for Point Hicks (Gauge 84070).

3.2.7 Alpine wetlands

Alpine wetlands are restricted to elevated areas >1200 m above sea level in the north east, south west and far east regions. Peatlands comprise two hydrologically distinct layers (Figure 3.40), an upper layer (acrotelm) and lower layer (catotelm). The acrotelm has a variable water content that is mostly maintained by direct precipitation (rainfall and snow melt). The catotelm is located below the water table and has very low hydrological connectivity with the acrotelm and remains fully saturated. During high precipitation, the acrotelm becomes saturated, but then drains to downstream or via evapotranspiration (Western *et al*., 2009). Very little water from the acrotelm recharges to the catotelm, and when the acrotelm drains there is very little release of stored water from the catotelm.

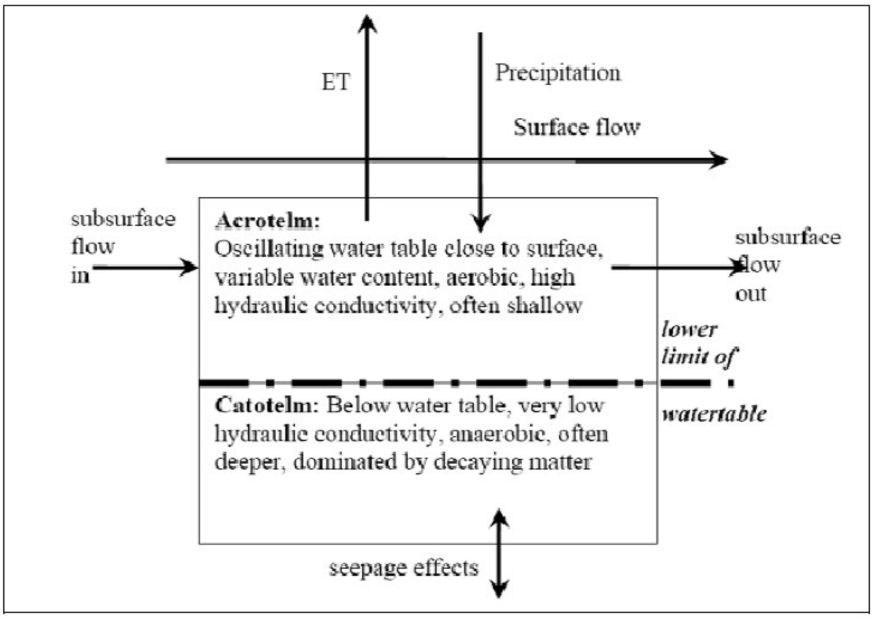


Figure 3.40 Two dimension peatland hydrology model (Grover, 2005)

Modelling of the impacts of climate change on peatlands in the Bogong High Plains has been conducted by White (2009). Reduction in precipitation leads to a reduction in the water table level that sustains the catotelm. Drying of the acrotelm can make peatlands more susceptible to bushfire and also invasion from dryland plant species. The dry scenario is predicted to reduce the area of peatland by 30% by 2030 (from 10.6 km^2 to 7.4 km^2) and by more than 63% by 2070 (to <3.9 km^2). Under a wet scenario no reduction in peatland area is predicted by 2030 but an 8% reduction is predicted by 2070. Under a dry scenario peatlands will contract to areas with a low topographic position as these are areas that tend to receive higher amounts of water and remain wetter for longer (White 2009).

4 Discussion and recommendations

The following sections provide a state wide summary of vulnerability of wetlands to climate change and a general discussion of risks to various wetland types. Management actions that would help in the mitigation of risks or support adaptation are indentified. Knowledge gaps, monitoring and other recommendations are provided at the conclusion of this chapter.

4.1 State summary of vulnerability

As a result of climate change there is predicted to be a reduction in rainfall across Victoria with the highest reductions being in the north and west of the state and the lowest reductions in the far east. This translates to a large reduction in stream flow, again with the north of the state most affected and the far east least affected (Jones and Durak 2005, CSIRO 2007, Victorian Government 2010). Analysis undertaken for this study show that the reduction in rainfall and river flow translates to a large reduction in the frequency of stream flow events of the magnitude required to inundate river fed wetlands. Wetlands in the north and west of the state are likely to be most affected.

Predictions for impacts of climate change on groundwater levels are less well understood, although recent studies are addressing this (e.g. Barron *et al.* 2010, Crosbie *et al*. 2011). These studies show that groundwater levels respond to rainfall via recharge of the groundwater table, although the intensity of rainfall is likely to be a more significant driver of recharge than annual volumes per se. The extent of impact on groundwater levels due to reduced rainfall and hence reduced recharge is likely to depend on changes in the intensity of rainfall, the seasonality of rainfall patterns and also the size of the groundwater system. For large, regional scale groundwater systems the response of groundwater levels to reduced recharge is likely to take a long time to manifest (i.e. these systems are relatively well buffered) (Crosbie *et al*. 2011). However, small scale, local groundwater systems are likely to respond much more rapidly to declining rainfall and reduced recharge, as demonstrated in this project through correlations between rainfall and groundwater level trends and for some site specific studies (e.g., Stewardson *et al*. 2009). Hence, in these systems groundwater levels are likely to trend downwards much more rapidly in response to reduced rainfall. Wetlands that rely predominantly on groundwater from local groundwater flow systems are likely to be more immediately impacted by climate changed induced reductions in rainfall compared to wetlands that are associated with regional flow systems.

For alpine wetlands, modelling by White (2009) has shown the potential for a large reduction in the areas of alpine wetlands under a dry climate scenario and a retreat to lower topographic locations. Drying also makes alpine wetlands more vulnerable to bushfire impacts.

In coastal regions sea level will be the primary driver of wetland change; storm surges/storm tides will have an additional impact in some areas, particularly along the central Victorian coast from Port Phillip Heads to Wilsons Promontory, including embayments (McInnes *et al*. 2009). Changes in rainfall, freshwater inflows and temperature may also affect coastal wetlands (see Section 0 and also SKM (2011) for more detail). The most vulnerable wetlands will be those in intertidal zones where sea level rise will result in more permanent inundation and those located above the intertidal zone in areas of low topography that may experience an increase in inundation frequency from sea level intrusion. Where there is an opportunity for coastal wetlands to migrate inland as sea level rises then there will be a change in distribution of wetlands but the diversity of wetlands types should still be maintained at a landscape scale. However, if landward migration is constrained by topography or linear infrastructure like sea walls and levees, then there will be a significant decline in the area of coastal wetlands (see SKM 2011).

Wetlands most vulnerable to climate change will be those:

- Rainfall fed wetlands located in regions where reductions in rainfall are highest;
- River fed wetlands located on floodplains of rivers that will experience a large decrease in the frequency of high flow events;
- Groundwater fed wetlands associated with local groundwater flow systems;
- Alpine wetlands with high topographic elevation; and
- Coastal wetlands located within and just above the intertidal zone and areas of low topography adjacent embayments and estuaries and where landward migration is restricted due to topography or linear barriers.

For all inland wetlands, the primary impact of climate change, regardless of source water will be a reduction in the frequency and duration of inundation events and an increase in the duration of dry periods. The specific impacts on individual wetlands will depend on local characteristics. However, permanent wetlands will experience a more variable water regime with a shift towards a more seasonal wet and dry inundation pattern and may experience an increase in the number and /or duration of dry phases. Seasonal wetlands will experience a more intermittent wet phase and a longer duration dry phase. This may result in a shift in vegetation community structure away from flood dependent (aquatic and semi-aquatic) species to more flood tolerant species (see Section 0). Intermittent wetlands may experience a longer dry phase, although they are already adapted to a mostly dry regime, so from a biological perspective are likely to remain relatively unchanged. In summary, there will likely be a decrease in the number and area of permanent and seasonal wetlands and an increase in the number and area of intermittent wetlands.

At a regional scale, the regions were wetlands are most vulnerable are those where climate change will have the greatest impact on the frequency and duration of inundation events. Table 4.1 provides an assessment of indicative vulnerability by wetland type and water source across regions.

River fed wetlands in the north west region are most vulnerable, followed by river fed wetlands in the south west and north east (particularly those towards the western part of the region in the Goulburn River catchment). In the north west, the interval between river flow events that inundate wetlands is predicted to increase more than five-fold under medium climate change and fifty fold under stepped climate change. In other words, wetlands that currently receive water every one to two years will be inundated only once every 5 to 20 years. Permanent wetlands will become seasonal and seasonal wetlands will become more intermittent. Intermittent wetlands are already well adapted to long dry periods and so they are considered at lower vulnerability to change. In the north east and south west regions, impacts on river flow events that inundate wetlands are less severe, but even so, there is still predicted to be a two fold increase in the interval between inundation events. The majority of permanent and intermittent river fed wetlands are located in the north west region, while the majority of seasonal wetlands are located in the north east region.

For rainfall fed wetlands, the north west and south west regions are most vulnerable with annual rainfall reductions ranging from 6-9% for medium climate change by 2055 and 14-17% under stepped climate change by 2055. This is predicted to increase the interval between inundation events and promote a shift in wetland type towards more seasonal and intermittent wetlands. Across the state these two regions support the majority of rainfall fed wetlands and hence from a state perspective are also the regions of greatest vulnerability. Rainfall fed wetlands in the north east and south east are at moderate vulnerability, particularly under stepped climate change. In the north east, rainfall reductions range from 5-8% for medium climate change by 2055 and 10-14% under stepped climate change by 2055. In the south east, rainfall reductions range from 4-8% for medium climate change by 2055 and 7-14% under stepped climate change by 2055. In the far east, rainfall reduction is generally >5% and rainfall fed wetland are considered to have low vulnerability.

Table 4.1 Summary of wetland vulnerability by wetland type across regions (indicative vulnerability green-low, yellow-moderate, red-high, black-not applicable).

Wetland type	Primary water source	Area (ha)	number	% area of state's wetlands				
				North west	South West	North east	South east & Otways coast	Far East
Permanent	River	68752	1379	65.8%	14.5%	17.4%	2.2%	<1%
	Rainfall	15289	1486	31.2%	64.9%	1.5%	2.4%	<1%
	Groundwater	56938	413	19.2%	77.8%	<1%	2.4%	<1%
	Alpine	5378	1218			94.8%	3.8%	1.4%
Seasonal	River	117400	5935	39.6%	8.6%	48.4%	2.4%	1.1%
	Rainfall	38827	5710	31.6%	56.8%	2.8%	8.8%	<1%
	Groundwater	65031	2655	73.5%	22.0%	1.2%	2.9%	<1%
	Alpine	929	291			11.9%	87.6%	<1%
Intermittent / episodic	River	19922	401	82.8%	5.9%	9.7%	1.5%	<1%
	Rainfall	4185	96	93.5%	6.4%	<1%	<1%	<1%
	Groundwater	4645	60	94.0%	5.7%	<1%	<1%	<1%
	Alpine	182	31			100.0%	0.0%	0.0%
Coastal (saline)	Permanent lagoon/lake	36659	109		4.0%		81.2%	14.8%
	Inter tidal	10342	147		0.3%		98.2%	1.2%
	Intermittent / episodic - above mean high tide	23152	466		23.0%		73.3%	3.5%
Unknown		15899	78	0.6%	10.3%	16.4%	55.4%	17.2%
Total		483530	20475					

Groundwater fed wetlands most vulnerable are those associated with local groundwater systems. These groundwater systems respond rapidly to droughts and floods, and are most likely to respond rapidly to climate change because these systems do not have a storage capacity to buffer changes in recharge (DSE 2009c). In the short to medium term (10-50 years) wetlands associated with larger, regional scale groundwater systems are at less risk. Regional groundwater systems have large storage capacity and are more easily able to buffer changes in recharge (Crosbie *et al*. 2011). Analysis shows regional groundwater flow systems are less likely to respond to decadal decreases in rainfall and recharge. However, they may still exhibit a longer term response to climate change over the 50 to 100 year timescale. All regions support these types of wetlands, although lack of data on the specific numbers of wetlands associated with local or regional groundwater flow systems makes an assessment of specific vulnerability difficult. Hence, an overall medium level of vulnerability has been assigned. On a state basis, most groundwater fed wetlands are located in the south west and north west regions, so these areas are likely to be particularly impacted.

In addition to the impacts of reduced rainfall on groundwater levels, groundwater fed wetlands are also at risk from a fall in water tables due to over-extraction of groundwater for consumptive use. Climate change may exacerbate this risk whereby consumptive demand shifts from surface water sources to groundwater sources, accelerating the decline in water tables. This is a particular risk for wetlands associated with local groundwater flow systems. Strategies aimed at identifying groundwater systems at risk from over extraction and managing extraction volumes are being implemented through Victoria's Sustainable Water Strategies (e.g. DSE 2010b).

Alpine wetlands in the north east and south east are likely to be of medium to high vulnerability – they rely partly on local rainfall and any reduction in rainfall will impact on hydrological regimes. Although other climate change impacts may have a greater effect on alpine wetlands than specific hydrological changes. For example, increased frequency of bushfires and higher temperatures (White 2009), that cumulatively put alpine wetlands at high risk.

Coastal wetlands in the south west, south east and far east are all vulnerable to sea level rise and increased storm surge intensity and frequency. Areas most vulnerable due to a lack of opportunity for landward redistribution are around Port Phillip and Western Port Bays (constrained by infrastructure) and along the Otway and far east coasts (constrained by topography).

4.2 Change in wetland type, habitat and biodiversity impacts

As a result of climate change there is likely to be a reduction in the frequency of high flow occurrences and greater reductions in the number of years in which duration targets are met for river-fed wetlands, particularly in the north west of the State. Analysis shows that for most northern Victorian rivers there will be a reduction in the frequency of river flows that inundate wetlands. However, there is a large degree of uncertainty around some events and depending on the degree of temperature change, there could also be an increase in the intensity of rainfall events over parts of Victoria, which may result in intense flooding (CSIRO 2006). Moreover, using the last ten years as a template for the worst case climate change scenario may be misleading because no large rainfall and flood events occurred that would inundate most wetlands, hence they were not predicted to occur under the stepped-climate scenario. The reality is that inundation events will continue to occur (and indeed have occurred in the second half of 2010, and again in the first half of 2011), although not at the same frequency as under historical climate conditions.

Despite the above uncertainty, the general predictions do indicate a reduction in the frequency of flow and rainfall events that inundate wetlands with wetlands in the north and west of the state most vulnerable. During the drought experienced in Victoria from 1997 to early 2010, which forms the basis for the step climate change scenario, many have observed that once-permanent wetlands have dried and ephemeral wetlands have failed to fill at all. For example, in the south west of the State, Lake Colac was dry in 2009. Furthermore, permanent saline lakes in the same region have experienced decreases in water level and development of hypersaline conditions. Under climate change, reduced freshwater inflows to many of these lakes may result in near saturation salinity most of the time in the future (Leahy *et al* 2010).

A reduction in the frequency and duration of inundation will result in significant changes in plant and animal communities, particularly for permanent wetlands that change state to an alternating wetting and drying regime and seasonal wetlands that shift to a longer duration dry phase. These wetlands will lose species that require a frequent (or permanent) inundation for survival or critical life history requirements. These wetlands will also be less frequently connected to their primary water source and each other; reducing opportunities for movement and dispersal of a range of plant propagules and aquatic fauna and reducing genetic mixing (Nielsen and Brock 2009).

Table 4.2 summarises the preferred inundation frequency (dry phase interval) for a selection of representative wetland plants for a range of freshwater wetland EVCs (EVCs and representative species sourced from DSE (2009a), inundation frequencies are sourced from Roberts and Marston (2000) and Rogers and Ralph (2010)). Most wetland plants prefer frequent inundation, at least every 1-2 years. Most species can cope with less frequent inundation, out to once every 5-7 years, but few wetland species can persist when the frequency of inundation is less than every 10 years. In a study of seed bank longevity Brock (2011) reported the average dry survival time for wetland seeds as 7.4 years. If the duration of the dry phase consistently exceeds the preferred dry phase interval then seed banks will eventually diminish (Brock 2011). The analysis of changes in frequency of river flow events that inundate floodplain wetlands suggests that even under medium climate change predictions, this threshold is likely to be exceeded, particularly in the north west of the state. Wetlands that are currently inundated infrequently are unlikely to be as significantly impacted because species are already tolerant or adapted to long dry periods.

For aquatic fauna, a reduction in the area of permanent wetlands is a significant threat. For fish to survive in wetlands they require a permanent water regime or at least regular connection with permanent water (e.g. river channels). Some small bodied native fish are considered wetland specialists (e.g. Murray hardyhead and southern pygmy perch (Lintermans 2007)). A reduction in the area of permanent wetlands, and changes in water quality (e.g. through increased salinity due to reduced flushing events and increased evapo-concentration) will lead to a reduction in available habitat for a range of aquatic and semi-aquatic fauna and lead to a regional reduction in biodiversity.

Across most of Victoria, and in particular the north and north west, river fed wetlands are at high risk from climate change and it is expected that many wetlands will become permanently dry, or at best inundated very infrequently compared to historical inundation. These systems will lose aquatic and semi aquatic plant and animal species and become increasingly terrestrialised.

A further consequence of drying at the landscape scale is an increase in distance between water bodies. This has implications for dispersal of a range of wetland species, including aquatic insects that have a flying stage, some plant species that may have propagules dispersed by the wind or waterbirds (e.g., Raulings *et al*. 2011) and various fish, amphibians, turtles and tortoises. The greater the distance between water bodies the greater the risk to successful dispersal. Unfortunately, there is very limited data on optimal or maximum dispersal distance for various wetland species.

Research should be directed to determining dispersal requirements for a range of wetland biota and then establishing a conservation network of wetlands in each region that can be watered through works and measures actions which collectively create a mosaic of wetlands that maintains some of the key wetlands types in each region and also allows for ongoing dispersal opportunities that helps to maintain regional biodiversity. Works and measures actions could include alterations to commence to flows, construction of new inlet channels or linking to existing irrigation systems and through establishment and delivery of environmental water entitlements. Specific actions would depend on the individual wetlands identified for inclusion in the conservation network.

Table 4.2 Selected wetland EVCs, representative plants (DSE 2009a) and preferred frequency of inundation (dark shading indicates preferred dry phase interval, light shading indicates maximum dry phase interval) (representative species do not necessarily reflect critical life forms for specific wetland types).

Selected wetland types (EVC number)	Representative species		Inundation Frequency (years)												
			Permanent		Seasonal								Episodic		
	Scientific name	Common Name	1		2		3		4		5		10		20
Lignum swamp (EVC 104)	*Eragrostis infecunda*	Southern Cane grass													
	Marsilea drummondii	Common Nardoo													
	Eleocharis acuta	Common Spike-sedge													
	Muehlenbeckia florulenta	Tangled Lignum													
Plains sedgy wetland (EVC 647)	*Amphibromus nervosus*	Common Swamp Wallaby-grass													
	Eleocharis acuta	Common Spike-sedge													
	Potamogeton tricarinatus	Floating Pondweed													
	Carex tereticaulis	Hollow Sedge													
Red gum (EVC 292, 458)	*Amphibromus nervosus*	Common Swamp Wallaby-grass													
	Isolepis fluitans	Floating Club-sedge													
	Potamogeton tricarinatus s.l.	Floating Pondweed													
	Carex tereticaulis	Hollow Sedge													
	Juncus holoschoenus	Joint-leaf Rush													
	Drosera peltata ssp. peltata	Pale Sundew													
	Eucalyptus camaldulensis	River Red-gum													
	Villarsia reniformis	Running Marsh-flower													
	Schoenus tesquorum	Soft Bog-sedge													
	Eleocharis acuta	Spike-sedge													
Sedge wetland (EVC 136)	*Baumea juncea*	Bare Twig-sedge													
	Schoenus spp.	Bog Sedge													
	Baumea arthrophylla	Fine Twig-sedge													
	Lepidosperma longitudinale	Pithy Sword-sedge													
	Patersonia spp.	Purple Flag													
	Goodenia humilis	Swamp Goodenia													
Spike sedge wetland (EVC 819)	*Eleocharis acuta*	Common Spike-sedge													
	Crassula helmsii	Swamp Crassula													
	Triglochin procerum s.l.	Water-ribbons													
Tall Marsh (EVC 821)	*Azolla spp.*	Azolla													
	Typha spp.	Bulrush													
	Bolboschoenus spp.	Club Sedge													
	Phragmites australis	Common Reed													
	Lemna spp.	Duckweed													
	Cyperus spp.	Flat Sedge													
	Juncus ingens	Giant Rush													
	Cladium procerum	Leafy Twig-sedge													
	Potamogeton spp.	Pondweed													
	Schoenoplectus tabernaemontani	River Club-sedge													
	Amphibromus fluitans	River Swamp Wallaby- grass													
	Landoltia punctata	Thin Duckweed													
	Myriophyllum spp.	Water-milfoil													

4.3 Management options for wetlands

4.3.1 River fed wetlands in regulated catchments

Many river fed wetlands occur on rivers that experience regulation for water supply. In many of these rivers the lower floodplain reaches are already impacted by a reduction in the frequency of flows that lead to floodplain and wetland inundation as a result of upstream water extraction (e.g., the lower Goulburn River (Cottingham *et al.* 2003)). Irrigation and other rural infrastructure may have also isolated some wetlands from their primary water source (e.g. Hird and Johnson Swamps northern Victoria). In these systems, wetlands have already experienced a reduction in the frequency of inundation and they may be even more vulnerable to climate change compared to unregulated river systems. Furthermore, the more heavily regulated rivers also occur in parts of the State where climate change impacts are predicted to be greatest (e.g., the Goulburn, Campaspe, Loddon and Wimmera systems in the north and north west). However, wetlands located on regulated rivers and within regulated river catchments may be able to continue to receive water at an appropriate regime via the establishment of wetland environmental water entitlements and delivery via irrigation supply and drainage channels (e.g., the Kerang Lakes) or through the construction of wetland regulators or other infrastructure that enable water to be directed to wetlands at lower commence to flow levels and then held in there for recommended durations (e.g. lower Latrobe River wetlands and some wetlands located on Lindsay, Mulcra and Walpolla Islands in the Mallee region). Management actions in these systems should be targeted at:

- Establishing water management plans and environmental water entitlements for high value and strategic wetlands.

  High value wetlands are those that support important biological, social and economic values. In most regions these wetlands have already been identified and for some of them, water regime management plans and environmental entitlements are already established. Further work is required to indentify a network of strategic wetlands that collectively provide a range of wetlands types across the landscape that enable conservation of wetland types and associated biodiversity at a regional scale. Effort is then needed to establish water management plans, water delivery options/infrastructure and environmental entitlements to deliver water according to the desired regime.
- Management of other degrading factors such as stock access, grazing and cropping activities, weed infestation etc.
- Removal or modification of barriers (e.g. regulators, levees, block banks etc) to connectivity with source water systems and between wetland.

4.3.2 River fed wetlands in unregulated catchments

Compared to regulated rivers, there is higher uncertainty regarding impacts on wetlands associated with unregulated rivers and also for rainfall fed wetlands. Most unregulated rivers are small in comparison to the regulated rivers and modelling of climate change impacts on river flows has only been undertaken for predominantly regulated systems, so limited information is available for unregulated systems. Even with climate change, unregulated systems will continue to experience the full range of flow variability. However, it is important that in these systems actions are put in place that ensures that connectivity between rivers and wetlands is uninterrupted. Removing existing artificial barriers or lowering commence to fill levels may be options for helping to maintain current inundation frequencies by allowing wetlands to fill at lower river levels. These actions require case by case investigations and water management option development.

4.3.3 Rainfall fed wetlands

For rainfall fed wetlands (and indeed all wetland types), actions needs to be adopted that reduce the capture and diversion of what rainfall does fall on the local catchment. These actions include:

- Improved management of farm dams (e.g. through limits on the size of farm dams and the installation of low flow bypass structures to limit the amount of water captured in farm dams and diverted away from wetlands);
- Prevention, and where possible, reversal of local drainage schemes, especially where wetlands have been historical drain or local catchment runoff has been artificially diverted around and away from natural wetlands; and
- Management of other degrading factors such as stock access, grazing and cropping activities, weed infestation etc.

4.3.4 Groundwater fed wetlands

Groundwater fed wetlands associated with local flow systems are at most risk. Actions are required to improve identification of these wetlands types (this is currently being undertaken to some extent as part of the Groundwater Dependent Ecosystems Atlas project commissioned by the National Water Commission). Actions are also required to limit the cumulative effects of groundwater pumping on wetlands and land use change that may reduce recharge opportunities (e.g. plantation development). A number of relevant studies are currently being undertaken to develop a toolkit for managing the water regime of groundwater dependent wetlands and for developing management triggers to protect these wetlands types.

4.3.5 Alpine wetlands

Actions to manipulate the hydrological regime of alpine wetlands are limited due to their location in the landscape and reliance on a combination of rainfall and groundwater. However, complimentary actions to prevent degradation of alpine wetlands are warranted. Actions to prevent disturbance to the peat structure (e.g. through fire, physical damage etc), which can accelerate drying, are necessary. The work of White (2009) has identified alpine wetlands at most risk, and this should form the basis for prioritising areas for management actions.

4.3.6 Coastal wetlands

Of all wetland types, coastal wetlands (whose primary water source is the sea) have the greatest opportunity to adapt to climate change. Coastal wetlands will be lost through inundation, but where opportunities for landward migration existing they will re-establish at a new elevation relative to the new sea level. Management actions are needed to help facilitate this redistribution, and include:

- Land use assessments to identify specific areas where coastal wetlands can re-establish and planning scheme amendments to protect these areas so that new wetlands can establish over time; and
- Assessments of infrastructure constraints and consideration/incorporation of actions to assist wetland migration when designing and constructing new or upgraded existing coastal infrastructure. This is particularly relevant in the context of coastal planning and asset protection activities being undertaken in preparation of climate change impacts.

4.4 Other threats

There a range of other threats to wetlands associated with climate change. They are not discussed in detail but include:

- Changes in temperature that contribute to expansion or contraction in distribution of various species. For example, warming is likely to reduce the number of days when frosts are experienced. In coastal areas this may result in an expansion in the distribution of mangroves (Boon, 2009). Furthermore, warmer temperatures and increased CO_2 favour some C_4 and CAM plants over C_3 plants. Most Victorian plants are C_3 plants, whereas C_4 and CAM plants are those that prefer warmer climates and also well adapted to water stress, such as warm season grasses and succulents. Hence warmer temperatures, increased CO_2 and increased water stress could result in changes in species distribution. In coastal wetlands, the introduced and invasive *Spartina* spp. is a C4 plant whose distribution could increase, further threatening coastal saltmarsh wetlands (Boon, 2009).
- Changes in the intensity and frequency of extreme events. Climate change is expected to result in increases in the frequency and intensity of bushfires, more intense rainfall events and longer duration droughts (SKM, 2010), all of which may impact directly or indirectly on wetlands. Alpine wetlands are at particular risk from increased fire frequency and intensity (White 2009)
- Changes in hydrology and the frequency of wetting and drying are likely to lead to changes in water quality, particularly salinity.

4.5 Knowledge gaps, monitoring and research recommendations

This study represents a broad regional assessment of climate change impacts on water regimes of wetlands using existing information on predictions for changes in river flow, rainfall and sea level rise. A number of knowledge gaps / uncertainties exist in the analysis and recommendations are made for dealing with these knowledge gaps and for further research.

2. The analysis of climate change impacts on river flow was undertaken using modelled data of monthly flow. Events that inundate wetlands typically occur at the daily rather than monthly scale. Hence monthly data can mask higher flow events that occurred for just a few days but resulted in wetland inundation. However, the available modelling of climate change impacts on river flows has been undertaken at a monthly time step, not a daily time step, so data is not available to enable a daily time step analysis.

   Recommendation: If daily modelling of climate change impacts on flows becomes available then the analysis could be repeated and updated to reflect the more accurate data.

3. Analysis of change impacts on flow regime were only able to be completed for selected river system where climate change modelling has already been undertaken. These rivers were typically the larger, regulated rivers where water resource demand modelling has been undertaken to inform the development of sustainable water strategies. Hence, the analysis is biased towards these systems and may not adequately represent the impacts that climate change might have on flow in smaller and/or unregulated systems.

   Recommendation: If modelling of climate change impacts on flows in these smaller, unregulated rivers is undertaken in the future then the analysis of impacts on wetlands could be repeated.

4. Flow analysis was undertaken for selected river systems and was based on an assumption that high flows would inundate wetlands. The analysis was not based on an assessment of specific wetland commence to flow thresholds.

   Recommendation: If a more detailed analysis is required at the site level then it would be possible to repeat the analysis but instead of using an Average Recurrence Interval flow magnitude as the trigger for wetland inundation the analysis would be undertaken for specific flow thresholds known to inundate target wetlands. Catchment Management Authorities interested in the impacts of climate change on specific wetlands could use this approach, although the uncertainty around the use of monthly flow remains.

5. Rainfall analysis assumed that most rainfall fed wetlands in the landscape would be inundated if the area received the median cumulative winter rainfall. This assumption has not been tested. Furthermore, impacts of climate change o rainfall were based on estimates of the annual reduction in rainfall scaled down to monthly. The scaling did not include seasonal factoring and it is probable that climate change will have a seasonal effect on rainfall reduction.

   Recommendation: Future analysis needs to test the assumption around the magnitude of rainfall required to fill rainfed wetlands and also incorporate seasonal factoring in rainfall predictions. Testing of this assumption could be undertaken at the site scale for selected individual wetlands where information is available on the historical wetting regime that can be correlated with rainfall at a nearby gauging location.

6. Impacts of climate change on groundwater levels are not well understood. This study assumed that local groundwater systems that rapidly respond to decadal rainfall patterns will also respond to climate change whereas regional groundwater system that do not respond to decadal patterns in rainfall are less likely to affected by climate change. However, there is limited empirical information to support this assumption, analysis was based on examination of existing groundwater level data at a few sites and applied across a region. Furthermore, the mapping of local and regional groundwater systems is often at a scale that doesn't allow one to accurately assign a wetland to a particular groundwater system.

Recommendation: Research opportunities exist to further understand the response of groundwater to climate change, including the confounding impacts of recharge and evapotranspiration. In addition, improved mapping of groundwater systems and development of a more accurate GDE layer would greatly improve the analysis. As would more accurate correlation between specific wetlands and particular groundwater systems. Site specific investigations are required to gain a better understanding of the groundwater dependency.

7. Impacts on coastal wetlands are described in general. Coastal wetlands whose primary water source is marine derived have the capacity to respond to climate change by landward migration and redistribution. However, opportunities for landward migration are limited by topography and the presence of man-made barriers. For a broad regional project we have not identified specific locations where landward migration is or isn't possible as an adaptation response.

   Recommendation: Site specific investigations and mapping is required at the local scale to determine the specific impacts of sea level rise on coastal wetlands and to indentify local barriers to migration and hence specific adaptation potential.

8. We have assumed the wetlands have a single primary water source. However, it is most probable that wetlands receive water from several sources and that each source may play a defined role in wetland function. For example, groundwater may sustain the wet phase of a floodplain wetland but variability in water level is provided by regular overbank river inundation. For the regional assessment we have only assessed primary water source impacts.

   Recommendation: Site specific investigations could be undertaken at selected representative wetlands in each CMA area to better understand the interrelationships and interdependency between various water sources. Factors to consider are the roles each water source plays in wetland structure and function, the timing of such interdependency and the relative threats associated with climate change impact where a wetland is dependent on several water sources.

9. We have assumed that wetland plant and animal community composition and ecosystem structure and function is driven in large part by the existing water regime. Following on from this, a reduction in the frequency of wetland inundation (as indicated by the completed analysis) is predicted to lead to a change in wetland structure and function. However, there is great uncertainty around the ability of many wetland species to survive an increased dry phase interval. There is also uncertainty around other threats and the interactions between these and changes in hydrology associated with climate change, for example in relation to acid sulphate soils, invasion by pest species and changes in the distribution of C3 and C4 plants and changes in evapotranspiration amongst other things.

   Recommendation: An opportunity currently exists to undertake monitoring and research investigations around the resistance and resilience of wetland species and wetland function to prolonged dry phases. Many wetlands have been inundated during the second half of 2010 for the first time in 10 or 15 years. Surveys of these systems (e.g. Avoca marshes, rainfall wetlands on the Millicent Coast basin etc) should be considered to determine how they respond to this inundation and to benchmark community composition and where possible link this back to species present during previous inundation events. This information would be extremely useful in helping to understand how long wetlands can experience a dry phase before structure and function changes, and also provide information on other threats and interactions.

   Selected wetlands could be established as Sentinel Sites that can be used in long term monitoring of the impacts of climate change. Sentinel Sites should comprise of a range of wetland types and water sources in coastal areas and both regulated and unregulated catchments across each climate change region or CMA. They could act as early warning sites of impending change and also be used to monitor trends in condition as climate change impacts become established.

References

Barrett, R., Nielsen, D. L. and Croome, R. (2010). Associations between the plant communities of floodplain wetlands, water regime and wetland type. *River Research and Applications* **26**: 866–876.

Barron, O., Pollock, D., Crosbie, R., Dawes, W., Charles, S., Mpelasoka, F., Aryal, S. & Donn, M. (2010). *The impact of climate change on groundwater resources: The climate sensitivity of groundwater recharge in Australia*. CSIRO: Water for a Healthy Country Report to National Water Commission.

Bird, E.C.F. (1993). *Submerging Coasts: the Effects of a Rising Sea Level on Coastal Environments*, Wiley, Chichester.

Boon, P.I. (2009). *Changes in biodiversity – mangroves, saltmarsh and other marine-influenced coastal wetlands.* Unpublished manuscript.

Boon, P.I., White, M. and Sinclair, S. (2010). *Climate change impacts and amelioration strategies for Victoria's coastal vegetation (mangroves and saltmarsh).* Unpublished manuscript.

Boulton, A.J. and Brock, M.A. (1999). *Australian Freshwater Ecology*. Gleneagles Publishing, Adelaide.

Brock, M.A. (2011). Persistence of seed banks in Australian temporary wetlands. *Freshwater Biology* **56:** 1312-1327.

Cahoon, D.R., Hensel, P.E., Spencer, T., Reed, D.J., McKee, K.L. and Saintilan, N. (2006). Coastal wetland vulnerability to relative sea-level rise: Wetland elevation trends and process controls. *Ecological Studies* **190**: 273-292.

Casanova, M.T. and Brock, M.A. (2000). How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant Ecology* **147**: 237-250.

Corrick, A.H. and Norman, F.I. (1980). 'Wetlands of Victoria I Wetlands and waterbirds of the Snowy River and Gippsland Lakes catchment'. *Proceedings of the Royal Society of Victoria*. 91:1-15.

Corrick, A.H. (1982). 'Wetlands of Victoria III Wetlands and waterbirds between Port Phillip Bay and Mount Emu Creek'. *Proceedings of the Royal Society of Victoria*. 94(2):69-87.

Cottingham, P., Stewardson, M., Crook, D., Hillman, T., Roberts, J. and Rutherfurd, I. (2003). *Environmental flow recommendations for the Goulburn River below Lake Eildon*. CRC Freshwater Ecology and CRC Catchment Hydrology Technical Report 01/2003.

Crosbie, R.S., McCallum, J.L and Walker, G.R. (2011). *The impact of climate change on dryland diffuse groundwater recharge in the Murray-Darling Basin*. Waterlines Report Series No. 40. National Water Commission, Canberra.

CSIRO (2006). *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions*. Prepared by B.L. Preston and Jones, R.N. for the Australian Business Roundtable on Climate Change.

CSIRO (2007*). Climate change in Australia, Technical report 2007*. CSIRO and Bureau of Meteorology. http://www.climatechangeinaustralia.gov.au/technical_report.php

Dresel, P. E., Clark, R. Cheng, X., Reid, M., Fawcett, J. and Cochraine, D. (2010). *Mapping Terrestrial Groundwater Dependent Ecosystems: Method Development and Example Output*. Department of Primary Industries, Melbourne.

DSE (2008). Central Region *Sustainable Water Strategy*. Department of Sustainability and Environment, Melbourne

DSE (2009a). *Index of wetland condition. Assessment of wetland vegetation, update September 2009*. Department of Sustainability and Environment, Melbourne.

DSE (2009b). *Northern Region Sustainable Water Strategy*. Department of Sustainability and Environment, Melbourne.

DSE (2009c). *Regional Climate Change Projections for Victoria*. Department of Sustainability and Environment, East Melbourne.

DSE (2010a). *Wetlands.* Conservation and Environment. Department of Sustainability and Environment, Melbourne. Accessed 8 July 2010. URL: http://www.dse.vic.gov.au/DSE/nrence.nsf/LinkView/D9EDFB6E635B9867CA256EEC002282C6C302ABD71868C04CCA256EE70007AA53

DSE (2010b). *Western Region Sustainable Water Strategy*. Department of Sustainability and Environment, Melbourne.

Gitay H., Brown S., Easterling W. and Jallow B. (2001). *Ecosystems and their goods and services. Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken and K. S. White, Eds., Cambridge University Press, Cambridge, 237–342.

Grover, S.P.P., McKenzie, B.M., Baldock, J.A. and Papst, W.A. (2005). Chemical characterisation of peatland peat and dried peat of the Australian Alps. *Australian Journal of Soil Research* **43**: 963-971.

Heron, S. and Joyce, A. (2008). *Northern Victorian Wetlands: water requirements and impacts of climate change on the 27.6 GL flora and fauna entitlement and dependent wetlands*. Report prepared for DSE. Kellogg Brown & Root Pty Ltd.

Lawrence, R., Rutherfurd, I., Ghadirian, P., White, M., Coates, F. and Thomas, I. (2009). *The geography and hydrology of high country peatlands in Victoria Part 1. Geography and classification*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 173. Department of Sustainability and Environment, Melbourne.

Leahy, P., Robinson, D., Patten, R. and Kramer, A. (2010). Lakes in the Western District of Victorian and Climate Change. EPA Science Report. Draft Report. EPA, Victoria.

Lintermans, M. (2007). *Fishes of the Murray-Darling Basin: An introductory guide.* Murray-Darling Basin Commission, Canberra.

Lowe, L., Webb, J.A., Nathan, R.J., Etchell, T. and Malano, H.M. (2009). Evaporation from water supply reservoirs: An assessment of uncertainty. *Journal of Hydrology* **376**: 261-274

Jin, C., Cant, B. And Todd, C. (2009). *Climate Change Impacts on Wetlands in Victoria and Implications for Research and Policy*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 199. Department of Sustainability and Environment, Heidelberg, Victoria.

Jones, R.N. and Durack, P.J. (2005). *Estimating the impacts of climate change on Victoria's runoff using a hydrological sensitivity model.* CSIRO Atmospheric Research, Melbourne.

McInnes, K.L., Macadam, I. and O'Grady, J. (2009). *The effect of climate change on extreme sea levels along Victoria's coast.* A project undertaken for the Department of Sustainability and Environment, Victoria and part of the 'Future Coasts' program. CSIRO Marine and Atmospheric Research, Melbourne.

Neal, B.P., Lang, S. and Treadwell, S. (2011). *Interpreting the ability to meet daily environmental flow recommendations from monthly water resource models.* Paper submitted to the Australian Hydrology Symposium.

Nielsen, D. & Brock, M. (2009). Modified water regime and salinity as a consequence of climate change: prospects for wetlands of Southern Australia. *Climatic Change* **95**: 523-533.

Oechel W. C., Vourlitis G. L., Hastings S. J., Zulueta R. C., Hinzman L. and Kane D. (2000). Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming. *Nature* **406**: 978–981.

Page, K., Read, A., Frazier, P. and Mount, N. (2005). The effect of altered flow regime on the frequency and duration of bankfull discharge: Murrumbidgee River, Australia. *River Research and Applications* **21**: 567–578.

Raulings, E., Morris, K., Thompson, R. and MacNally, R. (2011). Do birds of a feather disperse plants together? *Freshwater Biology* **56**: 1390-1402.

Roberts, J. and Marston, F. (2000). *Water regime of wetland and floodplain plants in the Murray-Darling Basin: a source book of ecological knowledge*. CSIRO Land and Water, Canberra.

Rogers, K. and Ralph, T.J. (2010). *Floodplain Wetland Biota in the Murray-Darling Basin Water and Habitat Requirements*. CSIRO Publishing, Melbourne.

SKM (2006). *Western Wimmera Wetlands Classification – groundwater-surface water interaction*. Report to the Wimmera Catchment Management Authority.

SKM (2010). *Impacts to water quality in the Murray-Darling Basin arising from climate change: Water quality risks from extreme events*. Report by Sinclair Knight Merz for the Murray Darling Basin Authority.

SKM (2011). *Indicative Assessment of Climate Change Vulnerability for Estuaries in Victoria*. Report by Sinclair Knight Merz for the Victorian Department of Sustainability and Environment

Stewardson, M., Western, A. & Wallis, E. (2009). *The hydrology of Wetlands in the Strathbogie Ranges*. Report to Goulburn Broken Catchment Management Authority by the Department of Civil and Environmental Engineering, The University of Melbourne.

Vanderzee, M.P. (1998). *Changes in saltmarsh vegetation as an early indicator of sea-level rise*. In Greenhouse: Planning for climate change. Pearman G.I., Ed. CSIRO, Melbourne.

Victorian Government (2010). *Climate Change Impacts*. Climate Change Information for Victoria. Victorian Government. Accessed 23 March 2010. URL: http://www.climatechange.vic.gov.au/Greenhouse/wcmn302.nsf/LinkView/57A8049B13F0C6EFCA25719A0028D4840CC3BC22387CB40DCA2575BE0002E027#water

White, A (2009). *Modelling the impact of climate change on peatlands in the Bogong High Plains, Victoria*. Unpublished PhD Thesis, Melbourne University

Winter, T.C. (2000). The vulnerability of wetlands to climate change: a hydrological landscape perspective. *Journal of the American Water Resources Association* **36**: 305–311.

Western, A., Rutherfurd, I., Sirawardena, L., Lawrence, R., Ghadirian, P., Coates, F. and White. M. (2009). *The geography and hydrology of high country peatlands in Victoria Part 2. The influence of peatlands on catchment hydrology*. Arthur Rylah Institute for Environmental Research Technical Report Series No. 174. Department of Sustainability and Environment, Melbourne.

Appendix A Wetland dataset attributes

A.1 Attributes

A.1.1 Wetland dataset

Field Name	Description
Wetland_Id	Unique identification number of the shape
Name	Wetland Name (if applicable)
SOURCE	Data set the supplier interpreted to produce dataset
ID	Wetland identification number (0 if not applicable)
Src_data	Supplier of source data
Src_id	Unique wetland identification number from the source data set (Wetlands id correlates to Wetlands 1994 data set if present otherwise, object id from source data set)
Comments	Comments from supplier

A.1.2 Report dataset

Field Name	Description
Wetland_Id	Unique identification number of the shape
PWS	Wetlands primary water source
FreqInund	Frequency of inundation interpreted from Corrick's classification
Category	Corrick's classification code
XCategory	Corrick's category
XSubcat	Corrick's subcategory
EVC_GP	EVC group number
EVC_SubGP	EVC subgroup number
X_EVCName	EVC the wetland is in
X_GroupNam	EVC group name
X_Subgroup	EVC subgroup name
Basin	Basin name the wetland is located in
Flow_System	Ground flow system the wetland is located in, based on national GFS information
GFSstate	Ground flow system the wetland is located in, based on statewide GFS information
Shape_Area	System calculated area in square metres
Shape_Length	System calculated perimeter in metres

A.2 Analysis

A.2.1 Wetland dataset

Parameter	Data Set	Rule
Name	DSE Wetland 1994 DSE WetlandDir MCMA Wetland NECMA Wetlands WCMA Wetland	*Name* equals name in supplied data
SOURCE	DSE Alpine Bogs & Wet Heathlands DSE Wetland 1994 DSE WetlandDirMCMA Wetland NECMA Wetlands WGCMA Wetland WCMA Wetland	The name of the data source the shapefile originated from. WCMA Wetland status = Existing For Directory of Important Wetlands dataset, the Source corresponds to a wetland type code
ID	DSE Wetland 1994 MCMA Wetland NECMA Wetlands WCMA Wetland Update WCMA Wetland	Wetlands id correlates to Wetlands 1994 data set if present otherwise, object id from source data set
Src_data	DSE Alpine Bogs & Wet heathlands DSE Wetland 1994 DSE WetlandDir MCMA Wetland NECMA Wetlands WGCMA Wetland WCMA Wetland	Wetlands are sourced from the CMA provided data sets, where absent, used DSE Wetlands 1994 data set then the Directory of Important Wetlands then finally the Alpine Bogs and Wet Heathlands dataset. Wetlands from Directory of Important Wetlands whose name indicated it was a river were taken out of the dataset.
Src_id	DSE Wetland 1994 DSE WetlandDir MCMA Wetland NECMA Wetlands WGCMA Wetland WCMA Wetland	*Src_id* equals identification number used by datasource
Comments	WGCMA	

A.2.2Report dataset

Parameter	Data Set	Rule
PWS	DSE GMU250 DSE Wetland GDE DSE EVC_BCS100	Groundwater – Wetlands which intersect Wetland GDE Riverfed – Wetlands which intersect selected layers in GMU250 Rainfall – Wetlands which were not groundwater or riverfed Coastal – Wetlands which intersect coastal layers in GMU250 or wetlands identified from EVC data
FreqInund	This study	Interpreted from Corrick's classification and PWS
Category	DSE Wetland 94 WCMA Wetland	As per Wetland 94 except for wetlands WCMA Wetland If WCMA Class 94 = WCMA Class then Category = Wetland 94 category
XCategory	DSE Wetland 94 WCMA Wetland	As per Wetland 94 except for wetlands from WCMA Wetland If Category is the same for WCMA and Wetland 94, then XCategory = WCMA Wetland Category If Category has changed, then XCategory = WCMA Wetland Category
XSubcat	DSE Wetland 94 WCMA Wetland	As per Wetland 94 except for wetlands from WCMA Wetland If Category is the same for WCMA and Wetland 94, then XSubcat = Wetland 94 X Subcat If Category has changed, then Subcat is blank
EVC_GP	DSE EVC_BCS100	Determined from identity operation between wetlands data and EVC_BCS100
EVC_SubGP	DSE EVC_BCS100	Determined from identity operation between wetlands data and EVC_BCS100
X_EVCName	DSE EVC_BCS100	Determined from identity operation between wetlands data and EVC_BCS100
X_GroupNam	DSE EVC_BCS100	Determined from identity operation between wetlands data and EVC_BCS100
X_Subgroup	DSE EVC_BCS100	Determined from identity operation between wetlands data and EVC_BCS100
Basin	GA RBASIN	Basin = BNAME of basin the wetland is within
FlowSystem	BRS flowsyst	FlowSystem = Flow_System from GFS_National region the wetland is within
GFSstate	DSE gfs1m	GFSstate = Category code of GFS_State region the wetland is within

Appendix B Number and area of wetlands

B.1 Victoria

Number and percentage of wetlands by primary water source and frequency of inundation in Victoria

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in State	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Coastal	109	0.53%			426	2.08%	40	0.20%	147	0.72%	722	3.5%
Groundwater	413	2.02%	2655	12.97%	60	0.29%					3128	15.3%
Groundwater - Alpine	1218	5.95%	291	1.42%			31	0.15%			1540	7.5%
Rainfall Fed	1486	7.26%	5710	27.89%	96	0.47%					7292	35.6%
River Fed	1379	6.74%	5935	28.98%	401	1.96%					7715	37.7%
Unknown	23	0.11%	47	0.23%	5	0.02%	3	0.01%			78	0.4%
Grand Total	**4628**	**22.61%**	**14635**	**71.49%**	**988**	**4.83%**	**74**	**0.36%**	**147**	**0.72%**	**20475**	**100%**

B.1 Victoria (continued).

Total area and percentage of area of wetlands by primary water source and frequency of inundation in Victoria

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in State	
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
Coastal	36659	7.58%			22835	4.72%	317	0.07%	10342	2.14%	70153	14.5%
Groundwater	56938	11.78%	65031	13.45%	4645	0.96%					126614	26.2%
Groundwater - Alpine	5378	1.11%	929	0.19%			182	0.04%			6489	1.3%
Rainfall Fed	15289	3.16%	38827	8.03%	4185	0.87%					58301	12.1%
River Fed	68752	14.22%	117400	24.28%	19922	4.12%					206074	42.6%
Unknown	7389	1.53%	4654	0.96%	2569	0.53%	1287	0.27%			15899	3.3%
Grand Total	**190405**	**39.38%**	**226841**	**46.91%**	**54156**	**11.20%**	**1786**	**0.37%**	**10342**	**2.14%**	**483530**	**100%**

B.2 North West region

Number and percentage of wetlands by primary water source and frequency of inundation in the north west region

Primary water source	Permanent		Seasonal		Intermittent		Total in region		As % of number in whole state
	Number	%	Number	%	Number	%	Number	%	
Groundwater	**196**	**3.47%**	**1357**	**24.00%**	**44**	**0.78%**	**1597**	**28.2%**	**51.4%**
Rainfall Fed	**203**	**3.59%**	**1352**	**23.91%**	**71**	**1.26%**	**1626**	**28.8%**	**22.3%**
River Fed	**521**	**9.21%**	**1571**	**27.78%**	**337**	**5.96%**	**2429**	**43.0%**	**31.5%**
Unknown	**1**	**0.02%**	**1**	**0.02%**	**1**	**0.02%**	**3**	**0.1%**	**3.8%**
Grand Total	**921**	**16.29%**	**4281**	**16.29%**	**453**	**8.01%**	**5655**	**100.0%**	**27.6%**

Total area and percentage of area of wetlands by primary water source and frequency of inundation in the north west region

Primary water source	Permanent		Seasonal		Intermittent		Total in region		As % of area in whole state
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	
Groundwater	10922	5.68%	47807	24.86%	4367	2.27%	63096	32.8%	49.8%
Rainfall Fed	4773	2.48%	12261	6.38%	3912	2.03%	20946	10.9%	35.9%
River Fed	45237	23.52%	46447	24.15%	16495	8.58%	108179	56.3%	52.5%
Unknown	2	0.00%	2	0.00%	84	0.04%	88	0.05%	0.6%
Grand Total	**60934**	**31.69%**	**106517**	**55.39%**	**24858**	**12.93%**	**192309**	**100.0%**	**39.9%**

B.3 South West region

Number and percentage of wetlands by primary water source and frequency of inundation in the south west region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in region		As % of number in whole state
	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	
Coastal	12	0.21%			124	2.19%	3	0.05%	3	0.05%	142	2.5%	19.7%
Groundwater	185	3.26%	1019	17.97%	16	0.28%					1220	21.5%	39.0%
Rainfall Fed	277	4.88%	3000	52.90%	23	0.41%					3300	58.2%	45.3%
River Fed	145	2.56%	834	14.71%	12	0.21%					991	17.5%	12.8%
Unknown	9	0.16%	9	0.16%							18	0.3%	23.1%
Grand Total	**628**	**11.07%**	**4862**	**85.73%**	**175**	**3.09%**	**3**	**0.05%**	**3**	**0.05%**	**5671**	**100%**	**27.7%**

Total area and percentage of area of wetlands by primary water source and frequency of inundation in the south west region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in region		As % of area in whole state
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	
Coastal	1478	1.22%	-		5329	4.41%	5	0.00%	30	0.02%	6842	5.7%	9.8%
Groundwater	44278	36.64%	14339	11.87%	267	0.22%					58884	48.7%	46.5%
Rainfall Fed	9915	8.21%	22047	18.24%	267	0.22%					32229	26.7%	55.3%
River Fed	9973	8.25%	10086	8.35%	1183	0.98%					21242	17.6%	10.3%
Unknown	778	0.64%	864	0.72%							1642	1.4%	10.3%
Grand Total	**66422**	**54.97%**	**47336**	**39.17%**	**7046**	**5.83%**	**5**	**0.00%**	**30**	**0.02%**	**120839**	**100.0%**	**25.0%**

B.4 North East region

Number and percentage of wetlands by primary water source and frequency of inundation in the north east region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Total in region		As % of number in whole state
	Number	%	Numb er	%	Numb er	%	Numbe r	%	Numbe r	%	
Groundwater	2	0.05%	51	1.28%					53	1.33%	1.7%
Groundwater - Alpine	1025	25.79%	13	0.33%			31	0.78%	1069	26.90%	69%
Rainfall Fed	17	0.43%	47	1.18%	1	0.03%			65	1.64%	0.9%
River Fed	345	8.68%	2384	59.94%	51	1.28%			2780	69.95%	36%
Unknown			4	0.10%	3	0.08%			7	0.18%	9%
Grand Total	**1389**	**34.95%**	**2497**	**62.83%**	**55**	**1.38%**	**31**	**0.78%**	**3974**	**100.00%**	**19.4%**

Total area and percentage of area of wetlands by primary water source and frequency of inundation in the north east region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Total in region		As % of area in whole state
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	
Groundwater	349	0.43%	804	0.99%					1153	1.42%	0.9%
Groundwater - Alpine	5097	6.28%	111	0.14%			182	0.22%	5390	6.64%	83%
Rainfall Fed	227	0.28%	1072	1.32%	3	0.00%			1302	1.60%	2.2%
River Fed	11984	14.76%	56815	69.96%	1939	2.39%			70739	87.12%	34%
Unknown			133	0.16%	2480	3.05%			2613	3.22%	16%
Grand Total	**17658**	**21.75%**	**58923**	**72.57%**	**4423**	**5.45%**	**182**	**0.22%**	**81197**	**100.00%**	**16.8%**

B.5 South East and Otway Coast region

Number and percentage of wetlands by primary water source and frequency of inundation in the south east region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in region		As % of number in whole state
	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	
Coastal	57	1.16%			280	5.70%	15	0.31%	136	2.77%	488	9.94%	67.6%
Groundwater	25	0.51%	217	4.42%							242	4.93%	7.7%
Groundwater - Alpine	105	2.14%	277	5.64%							382	7.78%	24.8%
Rainfall Fed	988	20.13%	1303	26.55%	1	0.02%					2292	46.70%	31.4%
River Fed	364	7.42%	1114	22.70%	1	0.02%					1479	30.13%	19.2%
Unknown	8	0.16%	16	0.33%			1	0.02%			25	0.51%	32.1%
Grand Total	**1547**	**31.52%**	**2927**	**59.64%**	**282**	**5.75%**	**16**	**0.33%**	**136**	**2.77%**	**4908**	**100%**	**24.0%**

B.5 South East and Otway Coast region (continued).

Total area and percentage of area of wetlands by primary water source and frequency of inundation in the south east region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in region		As % of area in whole state
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	
Coastal	29754	37.96%			16890	21.55%	71	0.09%	10151	12.95%	56866	72.55 %	81.1%
Groundwater	1384	1.77%	1907	2.43%							3291	4.20 %	2.6%
Groundwater - Alpine	206	0.26%	814	1.04%							1020	1.30 %	15.7%
Rainfall Fed	363	0.46%	3421	4.36%	3	0.00%					3787	4.83 %	6.5%
River Fed	1513	1.93%	2785	3.55%	304	0.39%					4602	5.87 %	2.2%
Unknown	6424	8.20%	2289	2.92%			102	0.13%			8815	11.25 %	55.4%
Grand Total	**39644**	**50.58%**	**11216**	**14.30%**	**17197**	**21.94%**	**173**	**0.22%**	**10151**	**12.95%**	**78381**	**100%**	**16.2%**

B.6 Far East region

Number and percentage of wetlands by primary water source and frequency of inundation in the far east region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in region		As % of number in whole state
	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	Num-ber	%	
Coastal	37	15.6%			15	6.3%	21	8.8%	4	1.7%	77	32.4%	10.7%
Groundwater	5	2.1%	9	3.8%							14	5.9%	0.4%
Groundwater - Alpine	87	36.6%	1	0.4%							88	37%	5.7%
Rainfall Fed			8	3.4%							8	3.4%	0.1%
River Fed	4	1.7%	22	9.2%							26	10.9%	0.3%
Unknown	5	2.1%	17	7.1%	1	0.4%	2	0.8%			25	10.5%	32%
Grand Total	**138**	**58%**	**57**	**24%**	**16**	**6.7%**	**23**	**9.7%**	**4**	**1.7%**	**238**	**100%**	**1.2%**

Total area and percentage of area of wetlands by primary water source and frequency of inundation in the far east region

Primary water source	Permanent		Seasonal		Intermittent		Episodic		Tidal		Total in region		As % of area in whole state
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	
Coastal	5414	51.2%			561	5.3%	239	2.3%	120	1.1%	6334	59.9%	9%
Groundwater	6	0.06%	106	1.0%							112	1.1%	0.1%
Groundwater - Alpine	73	0.7%	4	0.04%							78	0.7%	1.2%
Rainfall Fed			26	0.2%							26	0.2%	0.04%
River Fed	44	0.4%	1250	11.8%							1294	12.2%	0.6%
Unknown	185	1.7%	1366	12.9%	5	0.04%	1185	11.2%			2740	25.9%	17.2%
Grand Total	**5722**	**54%**	**2752**	**26%**	**566**	**5.4%**	**1424**	**13.5%**	**120**	**1.1%**	**10584**	**100%**	**2.2%**

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