Potential impacts of Climate Change on the Swan and Canning rivers

Prepared for the Swan River Trust by the Technical Advisory Panel

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Preamble

During the 21st century the ecology and character of the Swan and Canning Rivers will change, forced by climate.

By mid-century, community visions will anticipate a river system materially different from today.

Goals for a healthy system will have adapted accordingly.

Broadly, change in the river system will be driven by the inter-play of warming, reduced river inflows and sea level rise.

Ecologically and hydrodynamically the river system will become more marine in character.

It is too early to reliably anticipate the pace of any systemic change but this should become clearer during the next few decades.

These changes will re-define future criteria of river health, productivity and foreshore connection.

This report is a first attempt to create scenarios projecting the main components of change, their possible systemic inter-actions and their management implications.

Executive summary

Climate change is evident as an influence on the Swan Canning river system and has already produced irreversible change. The rate of change is increasing relative to the past century and changes to the familiar river regime will become increasingly evident and significant as the century progresses. Tidal and non-tidal sections of the rivers will be altered by significantly diminished stream-flow with warming of the water bodies and surrounding environment. There will be changes in the seasonal timing of flows with smaller and later autumn/winter flows. Tidal reaches will also be affected by sea level rise and by superimposed storm surges.

The lower winter flows, especially during the transitions from salt water to fresh in spring and autumn, could prolong and exacerbate low oxygen conditions across significant lengths of the tidal riverine reaches.

The ‘marine’ nature of the tidal reaches, especially the riverine sections, will last longer (become more marine in nature), a change driven by already diminished stream-flows. This trend will be accentuated through the century by continuing low flows and accelerating sea level rise. Banks, foreshores and low-lying riverside infrastructure developments in tidal reaches will be altered or suffer from the impact of inundation from sea level rise and by flooding from storm surge associated with sea level rise of at least 0.5 metres, and possibly a metre or more, in this century.

The non-tidal reaches and inland waterways will be affected by the stress of warming and drying. The warming will progress at around 0.2OC per decade over the next 30 years and is likely to accelerate beyond that time. River flows and salt loads will continue to diminish under a continued drying trend. Bank vegetation and catchment vegetation will change under increasing moisture stress and fire regimes in the catchment will become more severe.

Winter flooding is not likely to increase and may diminish further, but it is more likely than not that summer flooding will not decrease and might in fact increase. Coupled with the impacts of moisture stress and fire, flooding in the upper reaches may be an agent of altered erosion and sediment regimes, even if winter flood flows are diminished. The summer and autumn ‘event’ flows will bring large amounts of fine sediments, organic matter and nutrients into the system at the time of the year when low oxygen levels and algal bloom problems are most likely to occur. The specific impacts will depend on the condition of the larger catchment and where the rain falls.

The climatic changes projected for the Swan Canning river system will have major impacts on the catchment, ecology, social values, infrastructure and economics during the next 20 – 70 years.

Water, sediment, nutrients and salt loads from the broader catchment to the rivers are expected to reduce with widespread drying. The hotter and more arid climate will alter the distribution of native vegetation and land use practices in the region. Fuel loads will take longer to accumulate but fire seasons will be longer.

The key impacts on the ecology of the Swan Canning river system will be driven by sea level rise and reduced streamflow, which will increase the period of salinity stratification and the penetration of marine water upstream. Key biological processes will be affected, including: biological oxygen demand; nutrient cycling; and sediment retention. Changes in the distribution and abundance of species are very likely and the seasonal patterns of productivity and food-web dynamics will almost certainly be altered. The lower estuary, which experiences marine conditions for much of the year will be least affected. The upper estuary will be most affected with increased and ongoing problems associated with eutrophication, such as algal blooms and fish kills.

The social values of the system are likely to be threatened by a reduction in passive recreational facilities through loss of beaches, wetlands and associated vegetation throughout the lower, middle and upper estuary. Loss of aesthetic value may occur due to a greater frequency of algal blooms and fish kills in the upper estuary, which will lead to public perception of an unhealthy environment.

Increased development of infrastructure to mitigate sea level rise, including seawalls, revetments and barrages will alter the current iconic Western Australian landscape to produce a more ‘European’ or ‘artificial’ landscape.

Because of the uncertainty involved it will be important to maintain good communications with river users and residents so everyone agrees and understands the means of adaptation and ways to increase system resilience.

The main economic impacts relate to the increasing costs of water quality management. Reduced water quality has already necessitated considerable investment in a range of remedial projects in the system. Climate change is likely to exacerbate eutrophication and fish deaths in the upper estuary, and increased river and land values may require corresponding increased costs associated with monitoring and intervention programs such as oxygenation.

The increased fish deaths and algal blooms may reduce the recreational amenity and value for recreational users, which may in turn have an impact on local businesses in the region.

Economic loss will also result from a need to protect, retrofit, repair or replace infrastructure due to increased sea levels and storm surges. In addition, mitigation or modification measures may be required to protect riverside suburbs into the future.

Adaptation refers to reducing or accommodating to the adverse impacts of climate change. The ability to adapt to climate change will be aided by the use of appropriate and robust information on key variables that may then be used to develop strategies for protection, accommodation, avoidance or retreat.

Key adaptation strategies for the Swan Canning river system include:

- Assessment of the vulnerability of foreshore areas to provide a sound basis for determining future planning setbacks, managing foreshore vegetation and erosion, and designing erosion control measures.
- Development and adoption of innovative technologies to improve water quality through oxygenation, trapping nutrient and ensuring adequate flows.
- Using monitoring and modelling to predict future changes by expanding monitoring into upstream areas where climate changes are most likely to occur.
- Improving our understanding of how fishes and their supporting ecosystems respond to changes and how these changes impact biodiversity, recreational and commercial values.
- Protecting infrastructure by incorporating sea level rises of 0.1 – 0.3 m into the design, maintenance or replacement of roads, river jetties, boat pens and ramps, sea walls and groynes.

Adaptive management will ensure the Swan River Trust and wider community are in the best possible position to deal with the impacts of climate change and maintain the valuable ecosystem integrity of the Swan Canning river system.

INTRODUCTION

In recent millennia the earth's climate has been characterised by a comparatively stable inter-glacial period. Consequently, throughout the 20th century, a supposition of climate stability has been adopted in the decision-making process. This conveniently simple and reassuring assumption is now questionable in light of the global consensus on climate change. It is particularly true where defensible planning policies need to be developed.

The Intergovernmental Panel on Climate Change [IPCC] Fourth Assessment Report (AR4) (IPCC, 2007a) presents the most authoritative statements on climate change to date[1]. It concludes that:

> *Warming of the climate system is unequivocal as now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level [IPCC 2007a; p. 5].*
>
> *Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely[2] due to the observed increase in anthropogenic greenhouse gas concentrations [IPCC 2007a; p. 10].*

Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century [IPCC 2007a; p. 13].

Human induced warming of our planet is clearly one of the most pressing environmental concerns of our age. Rising sea levels, shifting patterns of precipitation and altered frequency and magnitude of extreme events will have far reaching implications around the globe. These impacts will be particularly felt in coastal environments. While changes in climate are set to continue through the next 100 years and beyond, impacts are also of concern at current planning time-scales.

In Western Australia, human population centres are largely concentrated on estuaries and river systems. In the capital city of Perth, the Swan Canning river system serves as an important focal point with more than 1.5 million people residing in the wider catchment Like most heavily populated aquatic ecosystems, the Swan Canning river system has a long history of environmental stress, demonstrated by recurring algal blooms, low dissolved oxygen levels and seasonal fish deaths.

Planning, protection and management of the Swan Canning rivers system is coordinated by the Swan River Trust. The Trust recognises the potential impacts of climate change will alter the ecological function of the rivers and have implications for the way people interact with the system as a whole. In light of this, the current range of management practices employed in the catchment will need to accommodate a new understanding of the impacts of climate change in the region.

In this context, the Trust commissioned a background report to provide an overview of climate change impacts and potential adaptation strategies for the Swan Canning river system. The Swan Canning river system is here defined as the Swan Canning estuary above Fremantle Port and the rivers and their catchments that discharge into the estuaries. The current report was developed by the Swan River Trust Technical Advisory Panel, comprising 15 leading Western Australian scientists

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[1] It is important to note that the AR4 is the outcome of an exhaustive review process that strongly inhibits speculative conclusions and as a result is conservative in some predictions (e.g. sea level rise)

[2] In IPCC (2007), the following terms are used to indicate the assessed likelihood, using expert judgement, of an outcome:

Likelihood as % probability of occurrence

Virtually certain	Extremely likely	Very likely	Likely	More likely than not
> 99%	> 95%	> 90%	> 66%	> 50%
	Extremely unlikely	Very unlikely	Unlikely	
	< 5%	< 10%	< 33%	

from a diverse range of backgrounds, and consultants with relevant climate change expertise.

The overall objectives were to:

- provide an overview of the current state of climate science with reference to regional scenarios for Western Australia;
- examine how the projected effects of climate change may impact the Swan Canning river system and determine which environmental stressors are most likely to produce physical changes to the system;
- assess how the ecological, social and economic values of the Swan and Canning rivers are most likely to be affected by the projected changes in the future climate; and
- consider feasible and effective adaptation measures that may assist the Swan River Trust together with the local, State and Commonwealth governments and the community to protect the ecological health and community benefit of the Swan and Canning rivers.

The IPCC Summary for Policy Makers (IPCC 2007b) is a major reference for this report. In addition the CSIRO and Bureau of Meteorology scenarios for Australia have been considered to provide increased detail at the national level (CSIRO 2007). While the information presented represents the best available science, it must be interpreted with an understanding of three inherent sources of uncertainty:

- future, unpredictable, human behaviour on emission control;
- science limitations; and
- natural variability.

In light of these uncertainties, a projections-based approach considering a range of possible outcomes (also known as scenarios) is adopted here. This reflects the practical risk management approach adopted by the IPCC (Appendix 1). For the purposes of this report, climate change refers to any change during time, whether due to natural variability or as a result of human activity (IPCC 2007b).

Observed climate change is discussed in Chapter 2. Where possible, the cause of these observed changes is outlined separately but it is important to note that clear attribution is not always possible. The term anthropogenic climate change means change specifically attributed to human activity. Projections of climate change in Chapter 2 essentially deal with this anthropogenic element.

The impacts of climate change on the Swan and Canning rivers are outlined in Chapter 3, whilst adaptation strategies to address these impacts are discussed in Chapter 4. Chapter 5 discusses the role and implications of climate change in planning.

Overall, the report is intended as an overview of the important implications of climate change for the Swan Canning river system in conjunction with adaptation options and future research directions. The information presented here will be used as a basis for further work to support key management programs to protect environmental health and community benefit of the system. In this context, it provides a baseline for future activities by the Swan River Trust as it continues to manage the river system in the backdrop of new pressures associated with our changing climate. The report also mentions major ancillary changes such as population growth and water demand where there are important interactions with climate change.

1 Climate change observations & predictions

1.1 Global climate change observations

> *At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones* (IPCC 2007b; p. 18).

This section provides on overview of observed changes in climate at a global scale. The information presented here draws heavily from the Intergovernmental Panel on Climate Change Fourth Assessment Report, Summary for Policy Makers (SPM) (IPCC 2007b), and may be considered in conjunction with more detailed reports available from the IPCC website www.ipcc.ch(.)

1.1.1 Global air and sea temperatures

> *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years*. (IPCC 2007b; p. 5).

Mean global surface temperatures have increased by 0.76° C since 1850 (IPCC 2007b). During the last 50 years, the rate of warming has increased at an average of 0.13° C per decade with 11 of the past 12 years among the 11 warmest on record (IPCC 2007b).

The average content of atmospheric water vapour has also increased since the 1980s over land, ocean and the upper troposphere. This increase is broadly consistent with extra water vapour held in warmer air.

Global sea surface temperature anomalies have increased by 0.5° C during the past 30 years relative to the 20th century average (Figure 2). Recent findings suggest more than 80 per cent of surface warming is being translated into ocean heating down to depths of 3 km.

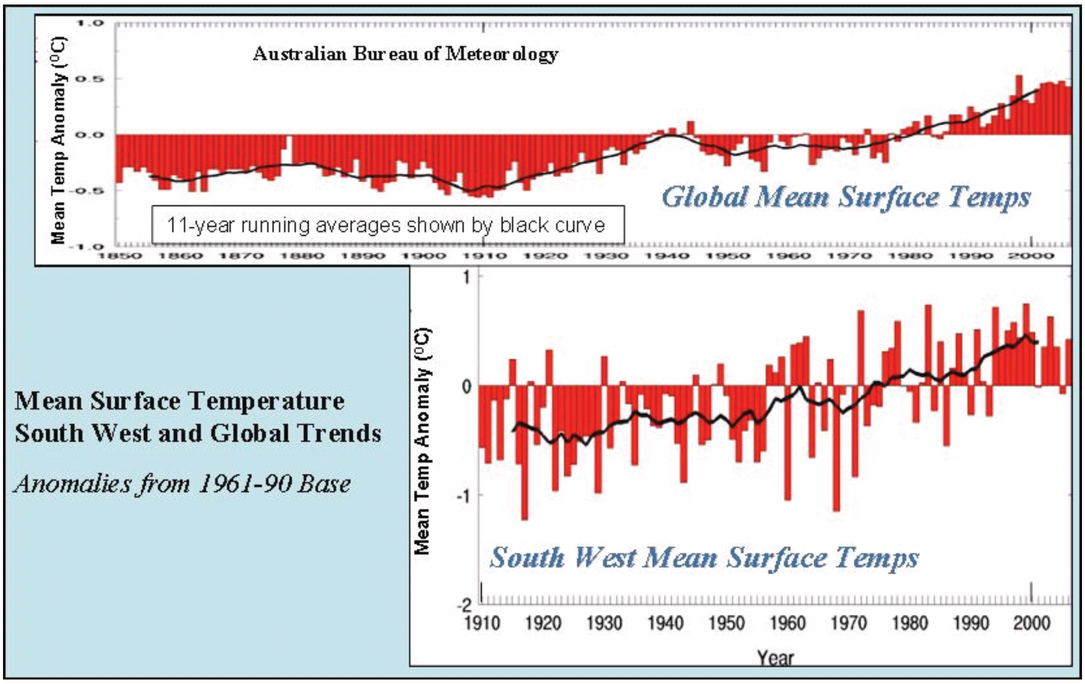

Figure 1 Mean surface temperature - south west and global trends: anomalies from 1961 - 1990 base *Source*: Bureau of Meteorology (2007)

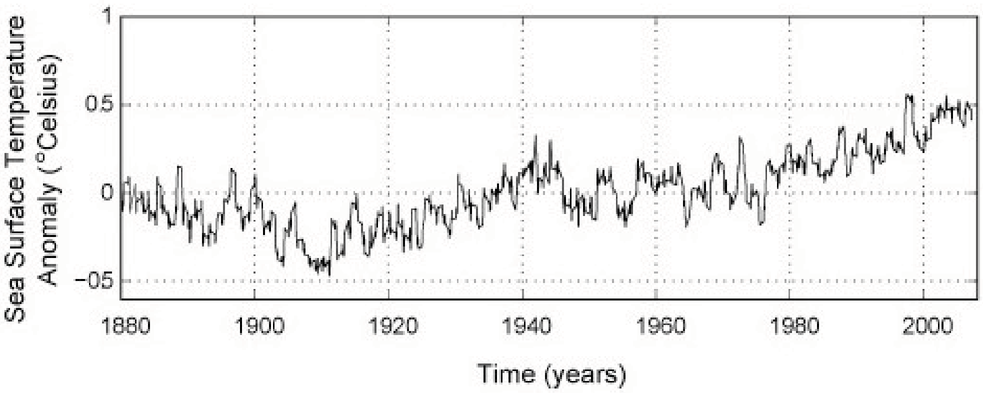

Figure 2 Sea surface temperature anomaly as a departure from the mean between 1900 and 2000 *Data source*: http://www.ncdc.noaa.gov/

1.1.2 Potential evaporation

Potential evaporation may add to vegetative stress in catchments, causing xeric (deficient in moisture) shifts and increased competition for water. Potential evaporation is the evaporation that would occur if moisture supply were unconstrained over a large area. ‘Actual evaporation’ is constrained by moisture availability. Pan evaporation, measured from small pans with unconstrained water availability, aims to give a measure of potential evaporation but can be affected by particularities of siting and is highly susceptible to changes in site environment Observed changes in pan evaporation over Australia are generally of low statistical significance. These issues give rise to circumstances in which reported regional or local trends may be as much related to the quality of sites selected for sampling purposes as they are for strength of signal from actual trends in potential evaporation. Pan evaporation data need to be regarded critically when used as an indicator of potential evaporation.

Observed trends in potential evaporation are thus complex and affected by measurement error. A decreasing trend in pan evaporation during recent decades in some countries seems contrary to projected trends in Global Climate Model (GCM) based estimates of potential evaporation and has been referred to as the ‘pan evaporation paradox’ (CSIRO 2007; p. 80). Australian regional trends in pan evaporation are not simply reflective of temperature rise but also reflect influences of regional trends in other factors, including cloud cover, wind and aerosol pollution. For example, in northern Australia pan evaporation observations display a small downwards trend apparently influenced by increased cloudiness, rainfall and effects of Asian aerosols. South western Australian observations have seen small increase in pan evaporations, consistent with broad expectations, but subject to the issues and errors outlined above.

1.1.3 Sea level rise

Total sea level rise during the 20th century was approximately 0.17 m [0.12 m to 0.22 m][3]. Further, global average sea level rose at an average rate of 1.8 mm per year from 1961 – 2003 with highest rates observed from 1993 – 2003 (~3.1 mm per year).

The various contributions to sea level rise for 1961 – 1993 and 1993 – 2003 respectively, are presented in Table 1. The sum of estimated climate contributions is consistent with directly observed total sea level rise within uncertainties of sea level measurement. These estimates are based on improved satellite and in-situ data relative to the previous IPCC Third Assessment Report (IPCC 2001).

Recent data indicate that losses from the ice sheets of Greenland and Antarctica are very likely to have contributed to sea level rise during the 1993 – 2003 period (see Table 1). Outflow from some Greenland and Antarctic glaciers has increased, draining ice from the interior of the ice sheets (IPCC 2007b). The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. Such dynamic ice loss explains most of the Antarctic net mass loss and approximately half that of Greenland. The remainder of the ice loss from Greenland is believed to have occurred when melting has exceeded accumulation from snowfall.

Table 1 Observed rates of sea level rise and estimated contributions from different sources
Source: IPCC (2007b; p.7)

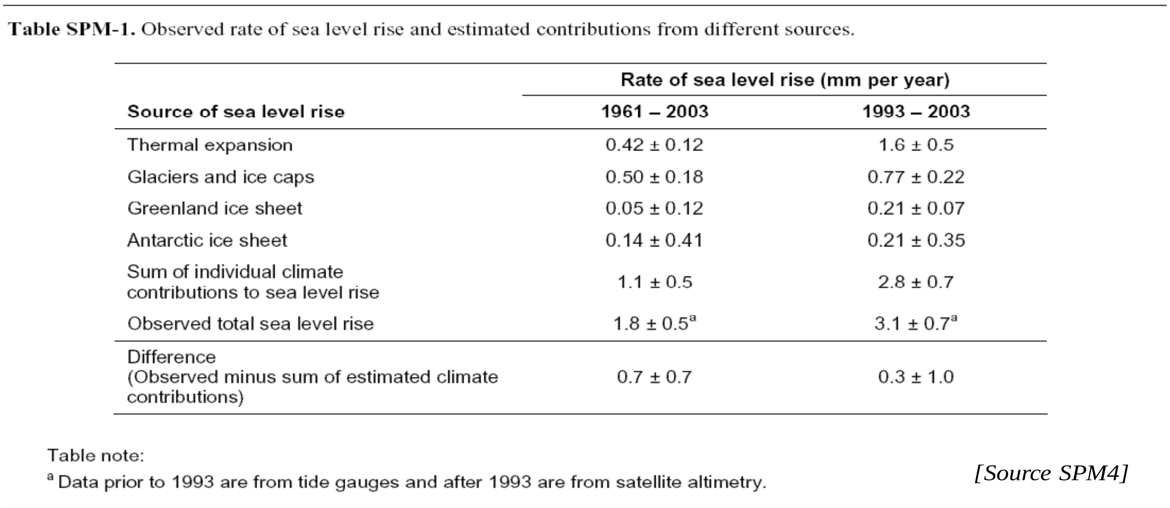

Table SPM-1. Observed rate of sea level rise and estimated contributions from different sources.

	Rate of sea level rise (mm per year)	
Source of sea level rise	**1961 – 2003**	**1993 – 2003**
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Table note:
[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry.

[Source SPM4]

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[3] In general, uncertainty ranges for results in the SPM are 90 per cent uncertainty intervals unless stated otherwise, i.e. there is an estimated 5 per cent likelihood that the value could be above the range given in square brackets and 5 per cent likelihood that the value could be below.

1.1.4 Weather patterns and rainfall

Long-term trends in precipitation have been observed from 1900 – 2005 over many parts of the world. Significantly increased precipitation was observed in eastern parts of North and South America, northern Europe and northern and central Asia. Conversely, drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia and south western Australia.

Large-scale changes in sub-tropical atmospheric circulation have been observed in the 1960s and 1970s. These are of particular relevance to south west Western Australia. Work associated with the Indian Ocean Climate Initiative[4] in particular, has reported changes in the Southern Hemisphere circulation that reduce the likelihood of storm development over south west Western Australia and largely explain observed decreases in south west winter rainfall. These changes include delayed northwards movement in the zone of cyclogenesis, which brings autumn, winter and spring rainfalls to south western Australia and an associated weakening of storm intensity and frequency.

1.2 Interaction between human activity and climate change

‘Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations’ (IPCC 2007b; p. 10).

This finding is based on a consideration of longer and improved records, an expanded range of observations, and better simulation of many aspects of climate available for the previous report of the IPCC (IPCC 2001). The results of new attribution studies evaluating whether observed changes are consistent with the expected response to external forcing were also taken into account.

Assessments from the IPCC (2007b) in relation to the likelihood of observed trends and human contribution to other more specific aspects of global climate are presented in Table 2. These trends are broadly evident in Australian climate observations (see CSIRO 2007; pp 17-29).

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[4] Indian Ocean Climate Initiative Stage 2: Report of Stage 2 Activity - www.ioci.org.au

Table 2 Recent global assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late twentieth-century trend *Source:* IPCC (2007b; p. 9)

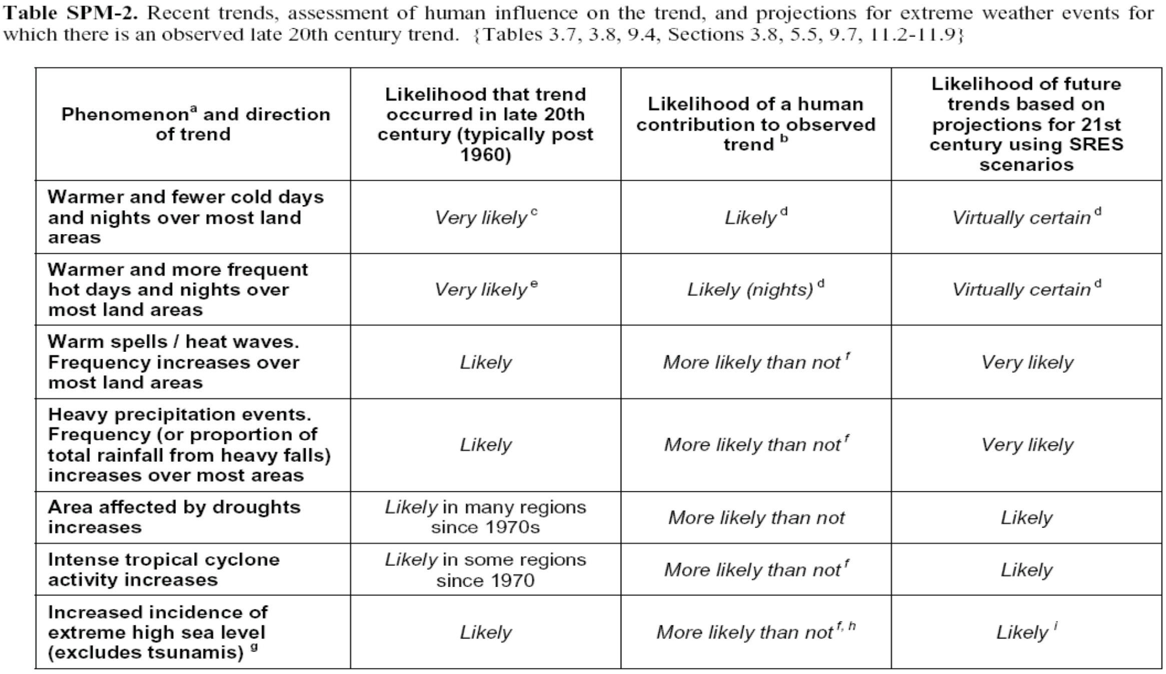


Table SPM-2. Recent trends, assessment of human influence on the trend, and projections for extreme weather events for which there is an observed late 20th century trend. {Tables 3.7, 3.8, 9.4, Sections 3.8, 5.5, 9.7, 11.2-11.9}

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend [b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely* [c]	*Likely* [d]	*Virtually certain* [d]
Warmer and more frequent hot days and nights over most land areas	*Very likely* [e]	*Likely (nights)* [d]	*Virtually certain* [d]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not* [f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not* [f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not* [f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis) [g]	*Likely*	*More likely than not* [f, h]	*Likely* [i]

a See Table 3.7 in IPCC (2007b) for further details regarding definitions.

b See Table TS-4, Box TS.3.4 and Table 9.4 in IPCC (2007b),.

c Decreased frequency of cold days and nights (coldest 10%).

d Warming of the most extreme days and nights each year.

e Increased frequency of hot days and nights (hottest 10%).

f Magnitude of anthropogenic contributions not assessed. Attribution for these phenomena based on expert judgement rather than formal attribution studies.

g Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

h Changes in observed extreme high sea level closely follow the changes in average sea level {5.5.2.6}. It is *very likely* that anthropogenic activity contributed to a rise in average sea level. {9.5.2}

i In all scenarios, the projected global average sea level at 2100 is higher than in the reference period {10.6}. The effect of changes in regional weather systems on sea level extremes has not been assessed.

1.3 Global emission scenarios

CO_2equivalents

CO2, the prime anthropogenic greenhouse gas (GHG), has risen from a pre-industrial atmospheric concentration of ~280 ppm to a current (2005) level of 379 ppm. Other key long-lived anthropogenic GHGs include methane, nitrous oxide and halocarbons. Anthropogenic aerosols (such as smoke haze, pollution and dust) have a shorter life in the atmosphere and a negative effect on solar forcing.

The net anthropogenic effect on radiative forcing is positive and currently equivalent to the effect of CO2 alone (Table 3).

Table 3 Atmospheric CO_2 concentrations and equivalent CO_2 concentrations of other GHGs (ppm) and aerosols Equivalent concentrations of long-lived GHGs and negative forcing of anthropogenic aerosols. *Data source:* IPCC (2007b)

Pre-Industrial	Current - CO_2 Concentration Equivalents (2005) in ppm CO_2			
CO_2 ppm	Greenhouse Gases		Aerosols	Net Equivalence GHGs +Aerosols
	CO_2 alone	All GHGs CO_2 GHG *All anthropogenic long lived GHGs incl CO_2*	CO_2 Aerosols *Dimming by Aerosols*	CO_2 Net *Net equivalence of all anthropogenic GHGs and aerosols*
~ 280	+379	+435	-60	+375

Special report on emission scenarios (SRES) and stabilisation emission scenarios

Future greenhouse gas emissions will be the product of demographic growth, socio-economic development and technological change, the extents of which are highly uncertain. In light of this, a range of scenarios has been developed, presenting alternative images of how the future might unfold. These are termed the SRES scenarios by the IPCC (2000) (Appendix 1) .

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of emissions targets of the Kyoto Protocol. An illustrative scenario was chosen for each of six scenario groups A1B, A1FI, A1T, A2, B1 and B2 in the recent IPCC (2007b) (see Appendix 1).

As the world has moved slowly towards targeted control of carbon emissions, it has also been useful to think in terms of stabilisation scenarios. Stabilisation scenarios are those that assume the world community sets and achieves a chosen concentration limit of carbon dioxide or carbon dioxide equivalent in the atmosphere.

Favoured stabilisation targets are 450 ppm or 550 ppm net anthropogenic carbon dioxide equivalent (a doubling of pre-industrial levels). These targets would seek to avoid ‘dangerous levels’ of global warming, seen as a real risk at around 2° C of warming (IPCC 2007b). The ‘safer’ 450 ppm level requires immediate and heavy reductions in emissions. Even the 550 ppm stabilisation level would need current, rapidly growing, CO_2 emissions to be returned to present levels by 2030 and steadily reduced to 50 per cent by 2100. In this context, the 550 ppm stabilisation is viewed as optimistic, whereas the 450 ppm scenario would seem highly unlikely.

Scenario selection for a realistic range of risks

Most available information on future climate change is based on the SRES scenarios. There is an approximate equivalence between these scenarios and different CO_2 stabilisation levels at 2100 (see Table 4). The A2 SRES however is not a stabilisation scenario. It increases more slowly in the early part of the century and continues with an upward slope at 2100. Consequently, the B1 SRES scenario will be used in this report as equivalent to the 550 ppm stabilisation scenario. The approximate CO_2 equivalencies are shown in Table 4.

The Technical Advisory Panel has chosen three of the SRES scenarios (B1, A1B and A2) as providing a realistic selection for consideration in future risk planning and management. These represent 550, 850 and 1250 ppm CO_2 and are the subject of further detailed projections (IPCC 2007b).

Table 4 CO_2 stabilisation equivalents of SRES scenarios

CO_2 stabilisation equivalents of SRES scenarios	
SRES scenario	Approximate CO_2 equivalent at 2100*
B1	**600 (~550)**
A1T	700
B2	800
A1B	**850**
A2	**1250**
A1F1	1550

*Approximate CO_2 equivalent concentrations ppm corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100.

Data source: IPCC (2007b)

In the opinion of the Technical Advisory Panel, in the spectrum of emissions scenarios outlined above, the A2 and B1 scenarios, for adaptation planning represent emissions tracks that are not extreme among the SRES scenarios. Rather, they can be considered as relatively realistic scenarios of GHG concentration outcomes consistent with:

- fragmented and weakly effective global responses (A2); or
- highly effective global responses aimed at achieving ‘safe’ levels of stabilisation (B1).

The implied political failure under an A2 stabilisation level is not so extreme as to imply continuation of business-as-usual growth. In the B1 level stabilisation scenario, global action is not so strong as to achieve assured avoidance of dangerous levels.

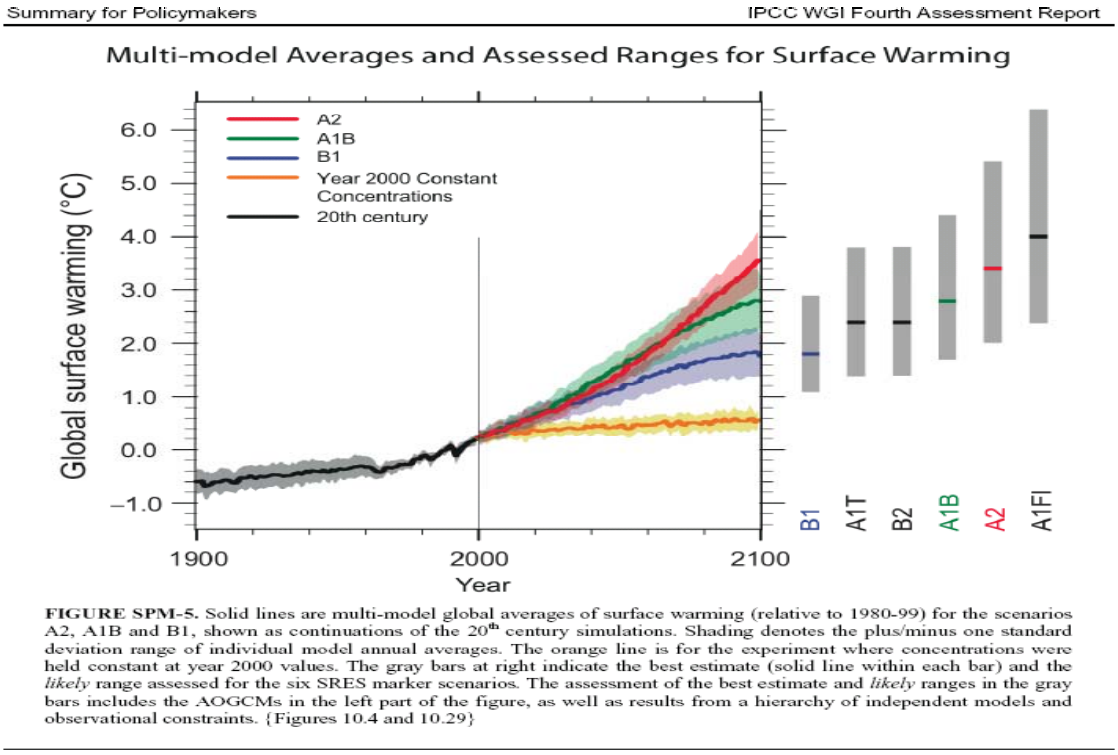
In forming judgements on the ‘realism’, ‘optimism’ or ‘pessimism’ of these scenarios it is important to note that, since establishment of the SRES scenarios in 2000, the global emissions outcomes have been tracking at the most extreme of the SRES scenarios, i.e. A1F1 (rapid growth under fossil fuels). As each year passes, the emissions reductions necessary to stabilise cumulative greenhouse gas concentrations below dangerous levels becomes more and more challenging for the global community. If stabilisation is to be achieved, the window of opportunity is small.

The next few decades are anticipated to be representative of high emission scenarios before, optimistically, very vigorous and highly effective global emissions reductions ‘kick-in’, bringing stabilisation in latter parts of the century. This reasoning suggests that, for those charged with anticipating and planning adaptive responses, expectations for the first half of this century should be weighted towards the higher end emission scenarios (A1B, A1F1, A2).

1.4 Global climate change projections

1.4.1 Air and ocean temperatures

Figure 3 shows the IPCC (2007b) projections of global mean surface warming for the three representative scenarios: A2, A1B and B1. Since the IPCC’s first report in 1990 (IPCC 1990), successive projections have suggested global average temperature increases of between about 0.15° and 0.3° C per decade for 1990 - 2005. This can now be compared with observed values of about 0.2° C per decade, strengthening confidence in near-term projections.



Summary for Policymakers IPCC WGI Fourth Assessment Report

Multi-model Averages and Assessed Ranges for Surface Warming

FIGURE SPM-5. Solid lines are multi-model global averages of surface warming (relative to 1980-99) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The gray bars at right indicate the best estimate (solid line within each bar) and the *likely* range assessed for the six SRES marker scenarios. The assessment of the best estimate and *likely* ranges in the gray bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}

Figure 3 Multi-model averages and assessed ranges for surface warming
Solid lines are multi-model global averages of surface warming (relative to 1980 – 1999) for the scenarios A2, A1B and B1, shown as continuations of the twentieth-century simulations. Shading denotes the plus/minus one standard deviation range of individual model annual averages. The orange line is for the experiment in which concentrations were held constant at year 2000 values. The grey bars at the right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. *Source:* IPCC (2007b; p. 4)

Table 5 Projected mean surface global warming for the key selected scenarios *Data source*: IPCC (2007b)

	Warming °C relative to 1990		
SRES scenario	2030	2070	2100
B1	0.8	1.6	1.9
A1B	1	2.2	2.8
A2	0.8	2.3	3.6
Range*	0.6 to 1.2	1.3 to 2.6	1.4 to 4.1
Mid range	0.9	2	2.8
Envelope of standard deviations of the three scenarios			

The projected rate for the next 25 years is ~ 0.2° C per decade. This follows warming of approximately 0.6° C in the 100 years to 1990 and an observed rate of ~ 0.2° C per decade since then. Notably, the short term projected rate of warming is only marginally affected by choice of global emission scenarios.

1.4.2 Sea level rise

The ocean acts as a sink for captured heat from the atmosphere and water from melting of glaciers and ice caps. Thermal expansion and physical movement and break-up of glaciers and ice caps thus drive sea level rise. These processes lag atmospheric warming and will continue for centuries while elevated atmospheric temperatures prevail.

Difficulties in assessing components associated with ice caps magnify uncertainties in sea level rise projections for this century. The IPCC estimates of the rate of rise are conservatively framed with an emphasis on the expansion and melt components rather than the currently incomplete science of physical dynamics.

The importance of the potential ultimate rise in sea level is outlined in the following statement (IPCC 2007b):

> *The last time the Polar Regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise. Global average sea level in the last interglacial period was likely 4 to 6 m higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3 to 5° C higher than present, because of differences in the Earth's orbit. The Greenland ice sheet and other Arctic ice fields likely contributed no more than 4 m of the observed sea level rise. There may also have been a contribution from Antarctica (IPCC 2007b; p. 10).*

The relevance of the aforementioned potential ultimate rise and/or possible physical acceleration of trends should be considered in any ongoing risk-management.

However, this is not possible if based only on information from the IPCC Fourth Assessment Report (due to a focus on the simplest and most readily calculable) components of change alone (IPCC 2007a).

Projections of sea level rise are presented in (IPCC 2007b). The confidence ranges are 90 per cent in respect to the components modelled. Models used to produce this data do not include uncertainties in climate-carbon cycle feedback nor do they include the full potential effects of changes in ice sheet flow. This is due to a lack of published literature on these aspects.

The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993 – 2003, but these flow rates could increase or decrease in the future. IPCC SMP (2007b; p. 15) included the following caveat to explain this uncertainty *'if this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table 6 would increase by 0.1m to 0.2m. Larger values cannot be excluded, but understanding of these effects was deemed as too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise in this century.'*

The mid-range estimate figures for a rise in this century, ignoring changes in ice flow, are 0.28 m, 0.35 m and 0.37 m for Scenarios B1, A1B and A2 respectively with a 90 per cent confidence range of 0.18 m to 0.51 m.

It is prudent to consider the upper bound limits of the IPCC sea level rise estimates as very possible outcomes due to the inherent conservatism in the IPCC estimates of rate of rise (noted above).

Considerations of the potential for accelerated rise, and planning with an eye to ultimate limits, relate primarily to longer term planning frameworks and iconic developments. However, mid-term planning also warrants consideration of higher rates given that projected rates of rise may be conservative due to the omission of some important components.

Table 6 Projected globally averaged surface warming and sea level rise at the end of the twenty-first century *Source:* IPCC (2007b)

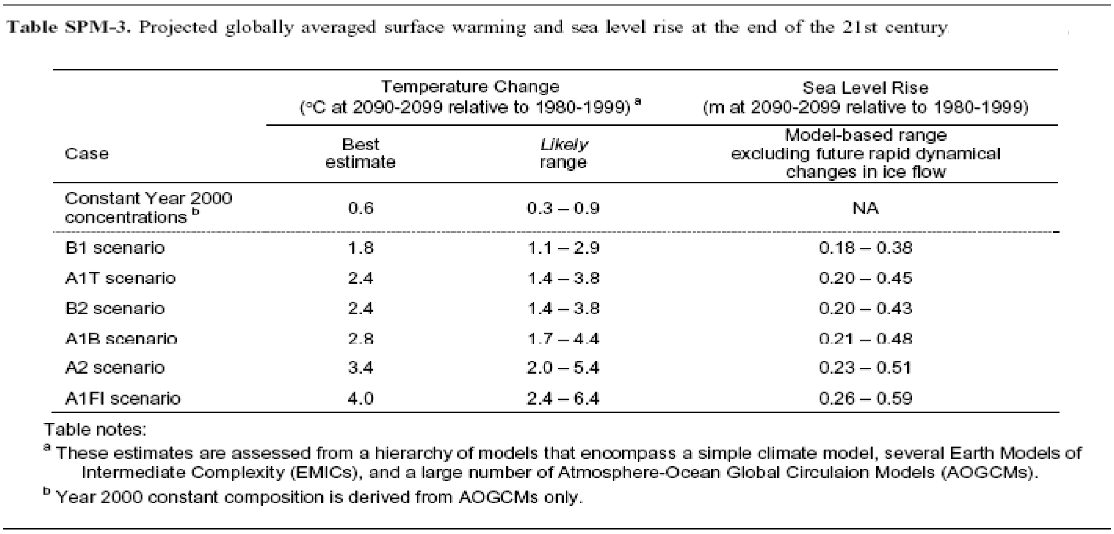


Table SPM-3. Projected globally averaged surface warming and sea level rise at the end of the 21st century

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulaion Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

1.4.3 Weather patterns and rainfall

Anthropogenic changes to atmospheric chemistry will affect large-scale circulation of the atmosphere, regional weather patterns and rainfall. Global research, and the regional research of IOCI, indicates changes in westerly systems that have a direct bearing on rainfall in the south west of Western Australia.

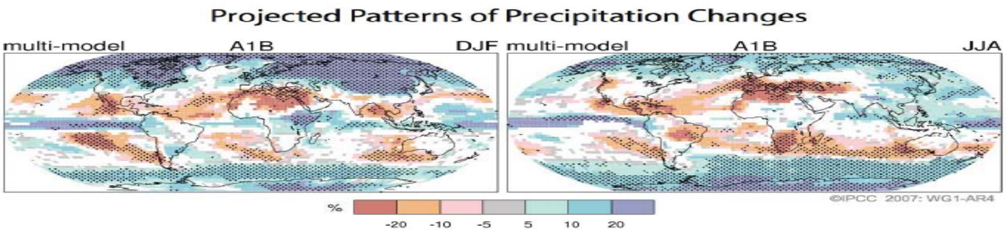


FIGURE SPM-7. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

Figure 4 -Projected patterns of precipitation changes
Relative changes in precipitation (in percent) for the period 2090 – 2099, relative to 1980 – 1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66 per cent of the models agree in the sign of the change and stippled areas are where more than 90 per cent of the models agree in the sign of the change. *Source:* IPCC (2007b)

An increase in global atmospheric mean evaporation and water vapour levels is also expected in conjunction with a subsequent gross increase in global annual precipitation. However, latitudinal shifts in circulation are projected to cause regional changes in atmospheric stability, storm generation and storm tracks with relative rainfall decline in some latitudes. Figure 4 shows model projections of wet and dry trends due to anthropogenic warming globally. Of importance to the current report is the projected winter drying in south west Western Australia.

1.5 Climate change observations for the Swan and Canning rivers

1.5.1 Air and estuary temperatures

Mean annual surface temperatures in the south west region increased approximately 0.6° C in the last century to 1990. This trend broadly matched the global and national trends. However, as the focus turns from global means to specific regions or localities the influences of random variability and local effects increase.

In the south west, rises in mean surface temperatures have occurred in autumn, winter, and spring rather than in summer. Mean minimum daily temperatures increased more than those observed in mean maxima thereby reducing the mean diurnal range. During the last 65 years in Australia there has been an increasing trend in the numbers of hot days (>35° C) and hot nights (>20° C) per decade. However, in the Swan Avon region, this upward trend has been relatively minor (~1 per cent and ~2 per cent per decade respectively). This result is mirrored in pan evaporations recorded in the south west, which also display an upward trend (Bureau of Meteorology 2007). This contrasts with trends in some Australian regions where changes in wind, cloudiness or aerosols appear to have offset the effects of warming on evaporation potential. However, as discussed in section 1.1.2 the trends in pan evaporation need to be regarded cautiously when viewed as an indicator of potential evaporation.

Global sea surface temperatures have also increased, particularly during the past 30 years (Figure 3 and Figure 5). This increase has been reflected in sea surface temperature data from the whole of the Indian Ocean (Figure 5). Global and Indian Ocean mean sea surface during temperature changes are similar with an almost linear increase of ~0.5° C over the past 35 years (Figure 5). In contrast, the ocean waters between Cape Leeuwin and North West Cape adjoining the West Australian coast, indicate a ~0.8° C rise in sea surface temperature during the same period (Figure 5).

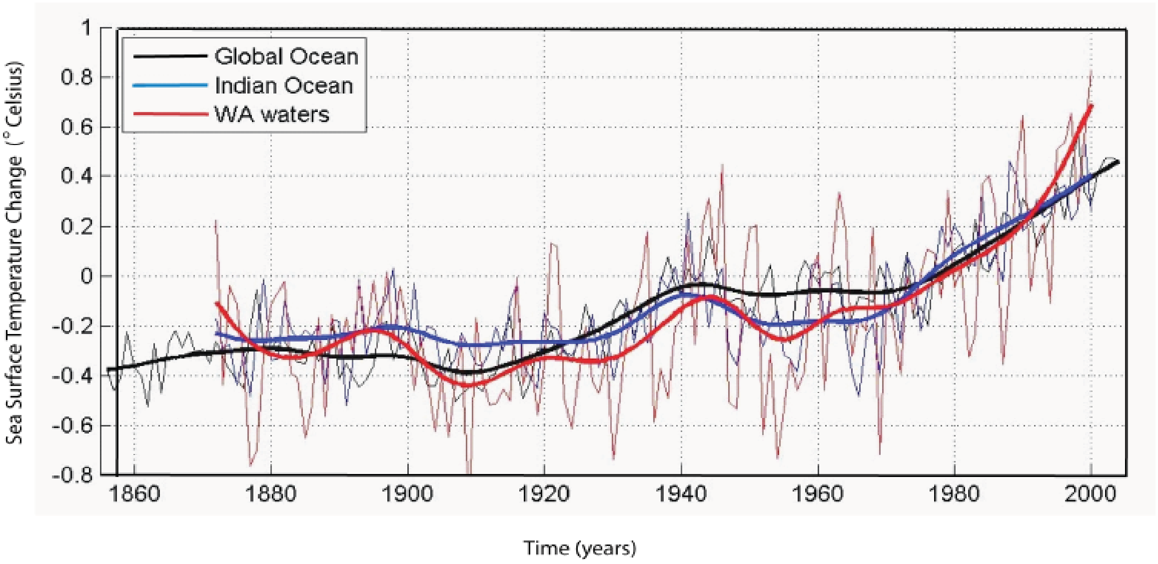


Figure 5 Recorded sea surface temperature changes for the global oceans, Indian Ocean and off the West Australian continental shelf *Source:* Eliot and Pattiaratchi (*in preparation*)

1.5.2 Storm surges

Storm surge is defined as the component of the water level that cannot be related to the periodic forcing of the moon and sun. It is also known as the tidal residual and is generated by changes in atmospheric pressure and wind stress. The Swan River experiences storm surges generated by storm systems impacting directly on the river (local forcing) as well as those that have an indirect impact on the region (remote forcing).

For example, storm surges generated by tropical cyclones along the Northwest Shelf propagate southwards along the coastline as continental shelf waves. In addition, weather systems that cross the coast during periods of five to ten days during summer and winter result in storm surges with a quasi-periodic forcing of water levels. The longer period associated with this water level change (order of days) results in surge propagation into the estuary with very little attenuation. This storm surge may be of the same order of magnitude as the tide and thus is a major component of water level variability in the estuary.

Storm surges have two major influences in the Swan Canning river system: (i) they provide a major forcing mechanism for water circulation that controls the distribution of salinity; and, (ii) extreme surge events result in flooding of low-lying areas. Hydrodynamic forcing is addressed in section 2.5.3.

Fremantle surge records since 1897 have been used to develop an index of storminess for the region (Figure 6). The index is based on the annual number of surges in conjunction with their magnitude. Energetic periods with a high number of significant storm surge events have been punctuated by relatively calm conditions. For example, peaks in storm surge activity were recorded from 1928 – 1936; 1973 – 1976; and, between 1992 and 2003. An increase in storm surge activity has also been observed since 1990 and is reflected in the elevated maximum water levels recorded in 2003 and 2004 (Table 7).

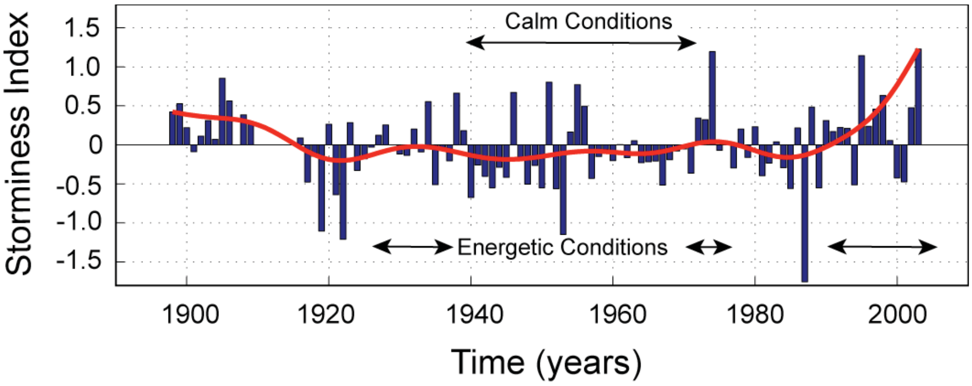


Figure 6 - Storminess index based on the storm surges recorded at Fremantle *Source:* Eliot and Pattiaratchi (*in preparation*)

Table 7 Highest water levels recorded at Fremantle 1897 – 2006 (metres above Australian Height Datum)

Date	Level (m)
16 May 2006	1.98
09 May 2004	1.90
18 May 1909	1.87
10 June 1956	1.86
20 Sep 1988	1.85

A reduction in the recurrence intervals of extreme water level at Fremantle has been observed in conjunction with the aforementioned variability in storm surge activity. This trend is mainly due to increases in mean sea level forced by global warming.

Water level data from the Barrack Street tide gauge illustrate a change in the recurrence interval of extreme water levels between 1930 – 1978 and 1988 – 2001 (Figure 7). For example, a water level of 1.70 cm, expected to occur every 10 years between 1930 – 1978, was expected to occur every five years between 1988 – 2001 (Figure 7). Similarly, a water level of 1.65 cm, with an expected seven to eight year recurrence interval for 1930 – 1978, would be expected to occur every two years at present. This change in the recurrence interval of storm surges may be directly attributed to the rise in mean sea level.

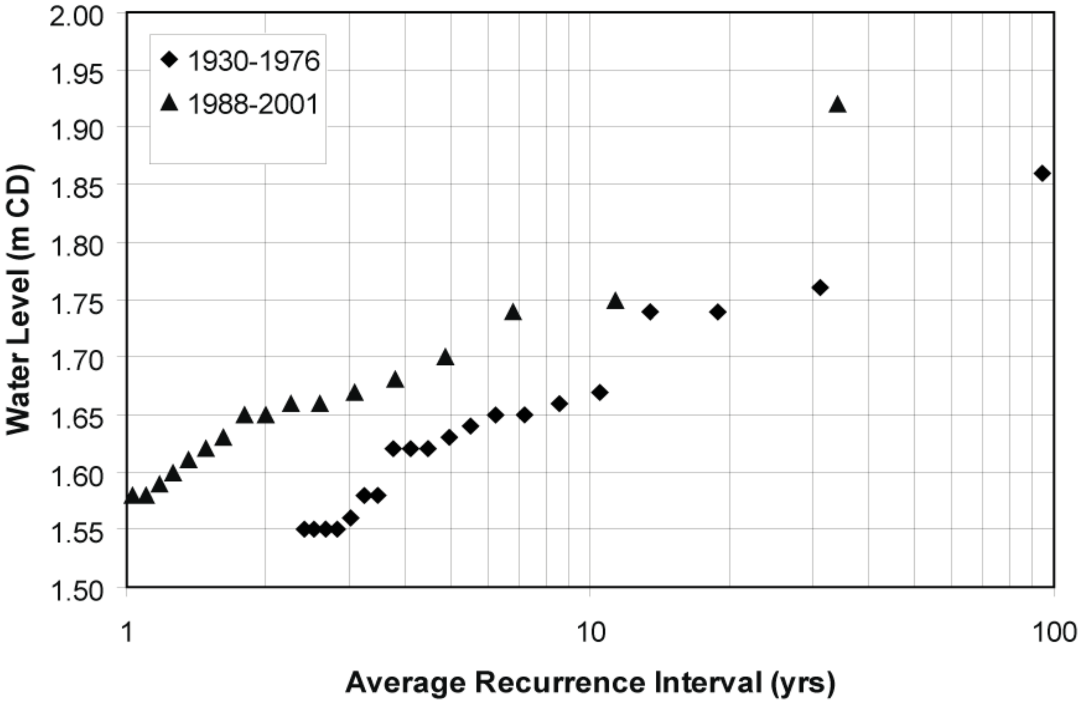


Figure 7 Recurrence intervals of water levels at Barrack Street *Source:* Eliot and Pattiaratchi (*in preparation*)

1.5.3 Hydrodynamics and the salt wedge

The pattern of water circulation in the Swan Canning river system results from a combination of the following factors:

- forcing dominated by freshwater discharge from the riverine section;
- water level forcing from the ocean boundary; and,
- gravitational circulation resulting from along-estuary gradients in density.

Changes to any major forcing mechanisms will result in changes to the hydrodynamic behaviour of the estuary.

Circulation in the Swan and Canning rivers is highly seasonal due to the seasonal nature of streamflow. In general, streamflow in winter flushes saline water out of the estuary. Along-estuary density gradients subsequently result in intrusion of saline water at the end of winter due to reduced streamflow and the presence of lower salinity levels in the upper estuary as compared to its lower reaches. The result is known as a salt wedge.

In years of high streamflow the salt wedge can be completely displaced from the upper estuary. The extent of river discharge associated with salt wedge displacement was established through a series of field investigations (Stephens and Imberger 1996). Results indicate that the salt wedge is flushed downstream when river discharge reaches $2x10^5$ m^3day^{-1} and completely removed from the upper estuary under a discharge of $20x10^5$ m^3day^{-1}.

However, with decreased rainfall and run-off during the past 30 years seasonal behaviour of the salt wedge has been altered and it is now consistently found in the upper estuary.

The location of the salt wedge has important and far-reaching implications for the water quality of the estuary. Strong vertical stratification results in inhibited mixing between the surface and bottom waters leading to low levels of dissolved oxygen. In addition, convergence at the tip of the wedge leads to higher concentrations of suspended matter, including phytoplankton.

In the absence of freshwater inflow, the location of the salt wedge is controlled by adjacent ocean conditions; in particular, changes in water level due to tides, storm surges and longer-term oscillations. Under the influence of a storm surge ocean water levels increase, resulting in inflow of saline water into the estuary and rapid upstream propagation of the salt wedge and the associated anoxic water. Under these conditions, several instances of fish kills have been recorded in the upper estuary. These water level conditions reverse when the storm surge abates.

1.5.4 Relative sea level rise

The Swan River region experiences an unusual water level regime in which tides, storm surges, and seasonal and inter-annual fluctuations are of similar magnitude with amplitudes of the order of 0.2 to 0.5 metres (Table 8).

Table 8 Major processes influencing sea level variability at Fremantle

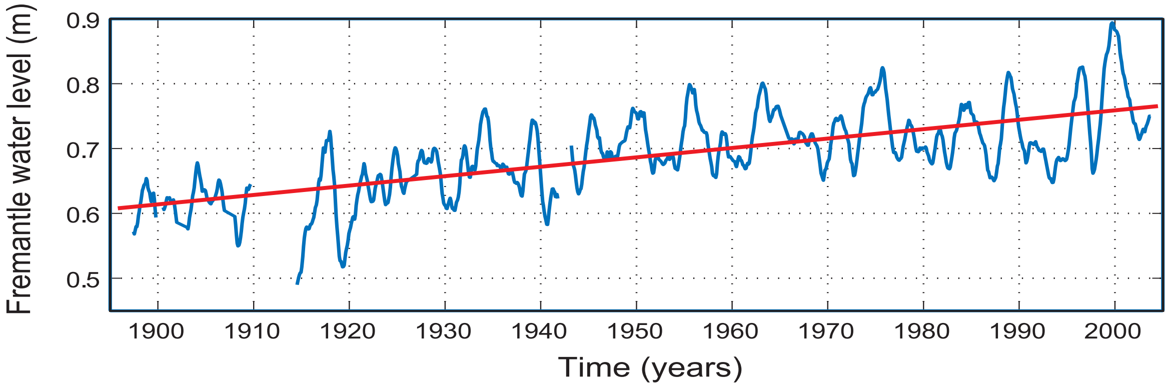
Processes	Time scale	Maximum amplitude
Astronomical tide	12-24 hours	0.80 m
Storm surge	1-10 days	0.80 m
Leeuwin Current	Seasonal	0.30 m
ENSO*	Inter-annual	0.30 m
Global warming	Decadal	0.015 m per decade

* El Nino Southern Oscillation

Fremantle sea level records are continuous since 1897 and represent the longest sea level data record in the southern hemisphere. This record indicates that mean sea level has risen at a rate of 1.54 mm per annum between 1897 and present (Figure 8). This rate of increase is similar to that observed globally (1.1 to 1.8 mm).

Although a trend of sea level rise has been observed during the past 100 years, removal of the linear trend from this record reveals periods dominated by the inter-annual variability of sea level linked to the ENSO phenomenon (Figure 9). From 1900 – 1952 cyclic periods of sea level increase and decrease between 10 to 14 years in length were observed. In addition, between 1952 and 1991 a decreasing trend was recorded. However, when considered in combination with the mean sea level rise, an almost constant mean sea level was observed. A reversal of this trend occurred between 1991 and 2004 with an apparent rapid mean sea level rise of 5 mm per annum – a rate more than three times the trend during the previous 100 years. This increased rate of sea level rise is associated with the maximum sea levels recorded at Fremantle in 2003 and 2004 (Table 7).

Figure 8 Time series of Fremantle sea level (one year running mean) with the linear trend of 1.54 mm per annum superimposed in red *Source*: Elliot and Pattiaratchi *(in preparation)*



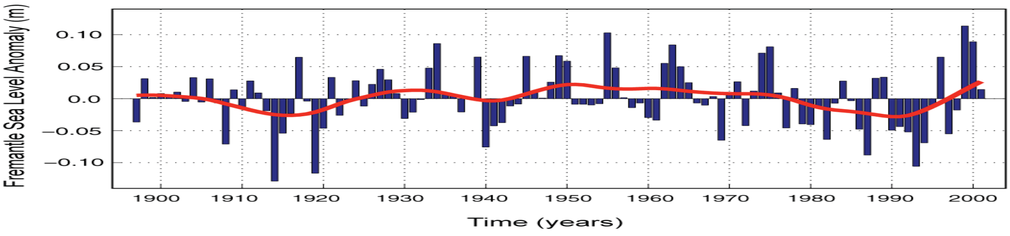


Figure 9 Time series of Fremantle sea level anomaly with the linear trend removed The red line shows the interannual variability in the record obtained by running a 19 year Hanning window to remove the long-term tidal effects *Source:* Elliot and Pattiaratchi *(in preparation)*

1.5.5 Seasonal total rainfall

A steep decrease in autumn/winter rainfall occurred in the early 1970s throughout the region, accompanied by a slight increase in spring and summer. These changes have been described in detail in reports and bulletins of IOCI and are illustrated in Figure 10. The changes are associated with changes in cyclogensis (see section 1.4.3).

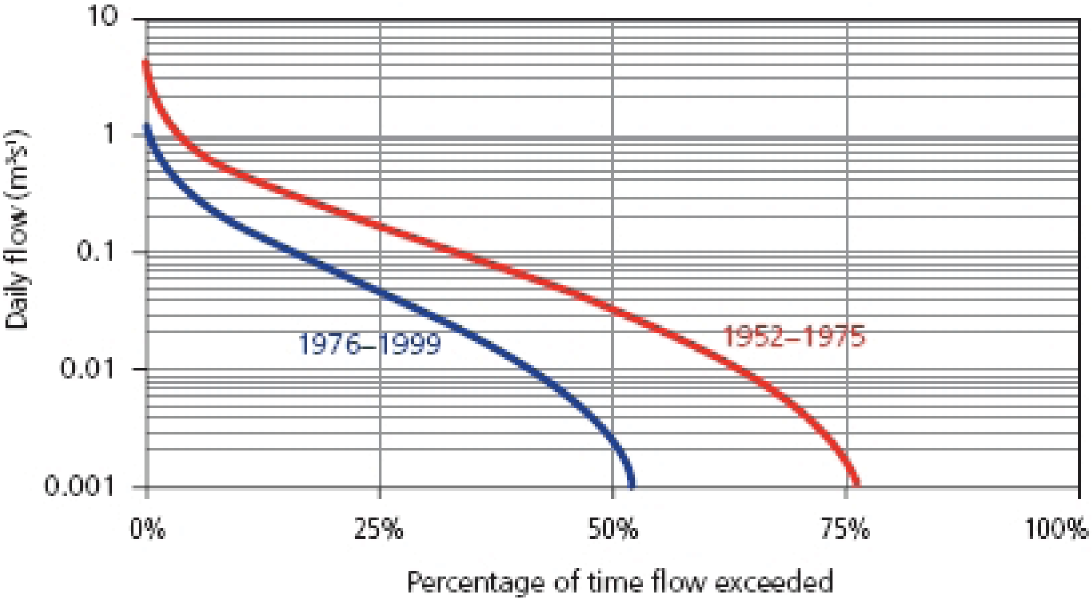


Figure 10 Change in daily flows for 1952 – 75 compared with 1976 – 99 for Yarragil Brook near Dwellingup *Source*: IOCI (2005b)

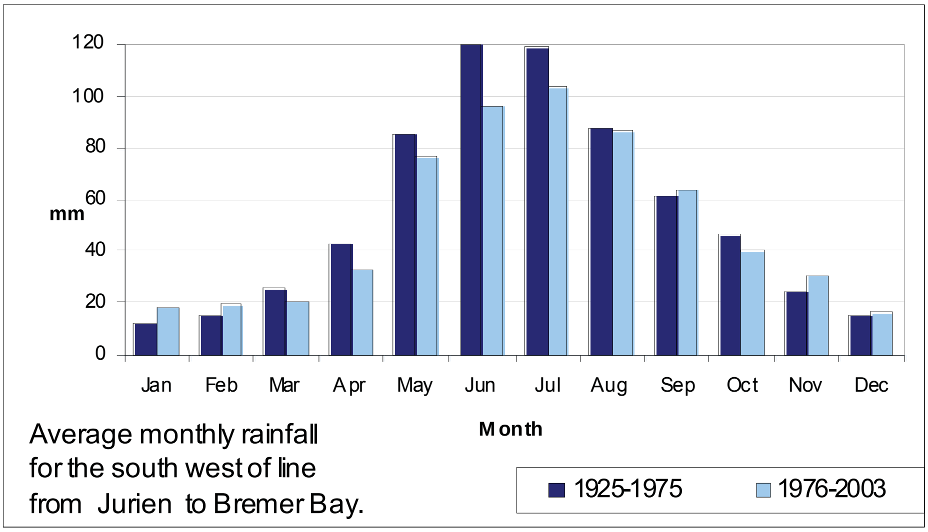


Figure 11 Average monthly rainfall for south west of a line from Jurien to Bremer Bay *Source: IOCI (2005a)*

Regional average rainfall for winter months decreased by 10 per cent during this period while rainfall from May - July decreased by 15 per cent (Figure 11). Although records for the last decade indicate further drying, a longer timeframe is necessary to assess whether the observed changes are statistically significant.

1.5.6 Annual and daily river flows

Regional streamflow has markedly decreased as a result of diminished winter rainfall. In extreme cases this has equated to more than 50 per cent reduction of runoff into metropolitan catchments. In general, the greatest change is observed in the catchments draining higher rainfall areas. Overall, these variations in flow have been observed from month to month as well as at an annual scale.

An example of change in daily stream flow between 1952 and 1999 is illustrated in Figure 10. A comparison of flow duration curves for 1952 – 1975 and 1976 – 1999 indicates that the river is dry more frequently in recent years.

1.5.7 Extreme rainfall and flooding

While changes in seasonal records have been apparent, a significant shift in extreme rainfall is more difficult to ascertain. Although existing records give an insight into extreme events occurring at a relatively frequent scale (e.g. 1 to 10 years), the recurrence intervals of rare, disaster level events are significantly harder to determine.

Extreme winter rainfall events as a cause of winter flooding

A consistent decrease in annual and winter rainfall has been observed throughout the south west of Western Australia since the mid 1970s. In addition, rainfall records indicated that the occurrence of large storms in winter months had significantly decreased as had winter extremes in daily rainfalls. This was reinforced by research conducted by Li *et al.* (2005) who determined that winter extreme daily rainfalls with up to 50 year return periods have decreased since 1965. As with the aforementioned decrease in annual rainfall, it is likely that multi-decadal variability is contributing to these observed changes in extreme winter rainfall events.

In addition to the effects of discrete rainfalls, winter flooding is heavily influenced by antecedent conditions (how wet the catchment is before the storm event). For example, the major winter flood of 1964 is considered a 1-in-50 year flood event, but was the combination of two very wet winter months followed by a 1-in-20 year rainfall event. Antecedent wetness and regional groundwater levels are generally lower since the rainfall decrease of the mid 1970s. Monitoring of bauxite catchments has shown significant falls in regional groundwater levels (Croton, pers. comm.). This will have consequent implications for future flood magnitudes of all frequencies.

Extreme summer rainfall events as a cause of summer flooding

Research to date has not found a statistically significant trend in the change in summer rainfall extremes over time (e.g. Li *et al.* 2005 and other unpublished IOCI related studies).

Water Quality

In the recent report of water quality trend analysis for the Swan Canning river system, Henderson and Kuhnert (2004) used regression models to investigate the spatial and temporal trends of environmental variables from 1995 to 2004. The results are summarised in Table 9 for the major areas of the Swan Canning river system. The results suggest a decreasing trend in total and oxidised nitrogen and phosphorus throughout most of the system. There was also a general decreasing trend in chlorophyll-*a*.

Table 9 Major water quality trends in the Swan Canning river system from 1995 - 2004 *Source*: adapted from Henderson and Kuhnert (2004)

Variable sampled	Lower Swan estuary	Middle Swan estuary	Upper Swan estuary	Middle Canning estuary
Total nitrogen	⇩ s&b	⇩ s&b	⇧ b	no evidence of change
Nitrous oxides	⇩ s&b	⇩ s&b	⇧ s	⇩ s - Riverton Bridge
Ammonium	⇩ s&b	⇩ s&b	⇩ s&b	⇩s - Riverton Bridge ⇩b – Salter Point
Total phosphorus	⇧	⇩	⇧ s	⇩ s - Salter Point
Phosphate	⇩ s&b ⇧ Blackwall Reach	⇩ s&b	⇩ s&b	⇩s - Riverton Bridge
Chlorophyll-*a*	⇩ s surface > bottom	⇩ s surface > bottom	⇧ from 2003 surface > bottom	⇩s surface > bottom
PROFILES				
Temperature	Marked seasonal changes in temperature profile over time with surface temperature generally greater than bottom, other than during winter months. No strong evidence of change over time at any site.	some evidence of ⇧ in s & b	some evidence of ⇧ in s & b	Some evidence of ⇩ in s&b at Riverton Bridge
Dissolved oxygen	⇧ b ⇩ s less hypoxia	more variable and ⇧ potential for stratification	⇩ b ⇧ hypoxia in profile	⇩ s ⇩ b – Riverton Bridge only
Salinity	⇧ clear & significant ⇧ s ⇩ variability of profile between Blackwall Reach and Narrows Bridge	⇧ clear & significant ⇧ s – Narrow Bridge & Nile St ⇧ b – Nile St to Maylands Swimming Pool ⇧ variability St John's Hospital & Maylands Pool Greater stratification of salinity profile	⇧ variability	⇧ s – Salter Point

Note: the table above presents the major trends in the variables presented. Some site-specific parameters did not follow the trends presented in this table. Refer to Henderson and Kuhnert (2004) for site-specific trend analyses.

1.6 Climate change projections for the Swan and Canning rivers

1.6.1 Scenarios

The climate change projections developed in this report are based on the A2 and B1 global scenarios (IPCC 2007b). Two main scenarios are proposed for the Swan Canning river system of south west Western Australia and are labelled A2# and B1# throughout the following discussion. The scenarios are interpretations of A2 and B1 type global scenarios, based on local interpretive material from sources such as IOCI and CSIRO/Bureau of Meteorology studies, including studies commissioned by State Government agencies such as the Department of Water.

To interpret and expand IPCC scenarios to the local level and to reconcile with significant observed local change, input from a number of local and national studies has been used. In the case of rainfall and streamflow, some adjustments have been incorporated to recognise possible contribution of other anthropogenic factors (land clearing) as well as multi-decadal variability to ’apparent’ changes in the observational baseline. Priority has been given to any available local studies down-scaling from global forcing. However, large gaps remain in local interpretive material in keeping with the science underpinning the Fourth IPCC Assessment (IPCC 2007a). Where necessary, gaps have been filled through interpolating, extrapolating or factoring in available data. A key part of the regional interpolation process has been peer review of judgements.

The scenarios presented here are in a draft form and must be viewed as such. They are not predictions, but are plausible alternative circumstances that might be encountered in future river management. They seek to encompass a range of higher and lower levels of change judged, from an adaptive perspective, as realistic (not extreme) possibilities (see section 1.4).

In keeping with the Fourth IPCC Assessment (IPCC 2007a), the scenarios generally exclude consideration of possibly dangerous instabilities in global climate. As such, the scenarios are inclined towards conservative optimism with regard to extremes. This is a limitation in risk management as long-term time scales may require additional scenario considerations for effective decision-making.

Overall, the scenarios may be viewed as a preliminary tool to imply conditions that will force inevitable change in the regional environment. The scenarios should be refined and expanded by further work and dialogue subsequent to this report.

1.6.2 Broad qualitative expectations

Table 10 qualitatively tabulates the broad expectations for regional climate change and addresses the projected changes for south western Australia and the Swan and Canning river system.

Table 10 Observed and projected (south western Australia / Swan Canning river system) climatic or climatically associated trends from global human development[5]

Phenomenon and direction of trend	Likelihood that the trend established or consolidated in late 20th century	Likelihood that anthropogenic climate change has contributed to the observed trend	Likelihood of future trend under A2#/B1# scenarios
Accelerating atmospheric and ocean warming (now rising at 0.2°C per decade)	Virtually certain	Virtually certain	Virtually certain
Autumn seasonal rainfall decrease (signficant)	Very likelyVery likely	Likely	
Winter seasonal rainfall decrease (significant)	Very likely	Very likely	Extremely likely
Spring seasonal rainfall increase (small)	Low significance	No robust evidence	Likely decrease
Summer seasonal rainfall increase (small)	Low significance	No robust evidence	Small decrease more likely than not
Decrease in total winter stream-flows (large)	Virtually certain	Very likely	Extremely likely
Increased frequency of droughts	Very likely	Very likely	Extremely likely
Decrease in frequency/intensity of extreme winter rainfalls (1 to 10 year return period)	Likely	More likely than not	More likely than not
Increase in frequency/intensity of extreme summer rainfalls (1 to 10 year return period)	Small or non-existent Statistically inconclusive	No clear evidence	No clear evidence for significant change
Decrease in frequency/intensity of winter flood flows (Swan tributaries)	Extremely likely	Extremely likely	Likely

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[5] In this report the IPCC Third Working Group judgement assessment terminology is used:

Likelihood as % probability of occurrence

Virtually certain	Extremely likely	Very likely	Likely	More likely than not
> 99%	> 95%	> 90%	> 66%	> 50%
	Extremely unlikely	Very unlikely	Unlikely	
	< 5%	< 10%	< 33%	

Increase in frequency/intensity of summer flood flows (Swan tributaries)	No clear evidence	No clear evidence	No clear evidence for significant change
Accelerating sea and tidal estuary level rise	Virtually certain	Virtually certain	Virtually certain
Increase/decreased risk of storm surges which superimpose on sea level rise and flood flows	Uncertain- No conclusive evidence	Uncertain- No conclusive evidence	Uncertain- No conclusive evidence
Increase in extreme tidal estuary levels	Virtually certain	Virtually certain	Virtually certain
Increased frequency of warm spells and heat waves	Likely	Likely	Extremely likely
Increased potential evapo-transpiration	More likely than not	More likely than not	Likely
Vegetative change (xeric shift) in uplands catchments	Very likely	Very likely	Extremely Likely
Vegetative change (xeric shift) in coastal catchments	Unlikely **	Unlikely	Very likely
Increased fire hazard##	More likely than not	More likely than not	Extremely likely

** Observed change on coastal plain appears to have been dominated by non-climatic influences (so far)
Relates to underlying risk before management intervention

1.6.3 Air and estuary temperatures

Air temperatures

Projections for global mean temperature rises were outlined in Section 2.4.1. However, it is important to note that these increases will not be uniform across the globe. The Summary for Policy Makers (SPM) projects greater temperature increases in the northern hemisphere than in the southern hemisphere and greater warming at the poles. Modelling by CSIRO (2007; pp 57-58) and also modelling for the IPCC (2007b) show greater warming in the north west and inland of Australia than in the south west.

At the time of assembling this report, no detailed data were available to relate south west surface temperatures directly to the IPCC SPM scenarios. A coarse global trend map in the SPM (IPCC 2007b; Figure 6, p. 15) suggests that south west temperatures would project at approximately 0.8 of global means, whereas a report by IOCI (2005c) implies indirectly that this ratio may be nearer to one. Comparisons with CSIRO (2007) scenarios suggest a ratio of approximately 0.85 for Perth, Western Australia. The following table (Table 11) is constructed through reference to both the IPCC (2007b) and CSIRO (2007). The table assumes that the ratio of south west mean to global mean is approximately 0.85.

Table 11 Projected annual mean warming - south west (surface level) *Data source*: CSIRO (2007)

* Multi model means and 90 percentile ranges

NOTE: The italicised figures are the 90 percentile range of a multi-model ensemble

Scenario	Warming °C relative to 1990		
	2030	2070	2100
B1 δ*	0.8 *	1.4 δ *(1-2)* δ$^{\#}$	1.6 *
A1B δ*	0.8 δ *(0.6-1.2)* δ	2*	2.4 *
A2 δ*	0.8 *	2 *	3.0 *
A1F1	0.8 *	2.7 δ$^{\#}$ *(1.9-3.8)* δ	3.4 *

* Approximations on assumption that SWWA changes are 0.85 of projected global mean given in the SPM δ Perth figures from CSIRO, 2007, p 135

The number of hot days in the region has increased slowly. Model projections expect further increases in this century. Indicative figures of surface warming are presented in Table A3 (b) Appendix 1.

Estuary temperatures

Data limitations are apparent for projected changes in sea surface temperatures of the south west region, similar to those previously documented for atmospheric projections. Observed rises in sea surface temperatures adjacent to the Western Australian coast indicate a ~0.8^{o} C increase during the past 35 years (section 1.5.1 and Figure 5). Current General Circulation Models do not resolve features such as the Leeuwin Current, which has a large influence on sea surface temperatures off the Western Australian coast. Analysis of CSIRO MK3 coupled ocean/atmosphere model output indicates that for the A2 scenario the predicted sea surface temperatures off Western Australia would increase by ~0.9^{o} C in the decade 2061 – 2070 compared with the period 1991 – 2000 (Figure 12). This latter figure is consistent with ranges recently published by CSIRO (2007; p. 100) and are incorporated in Table A3 (b) of Appendix 1.

A strong relationship between temperature and Dissolved Oxygen (DO) consumption has been demonstrated in Swan Canning river system sediments during benthic chamber deployments (G. Douglas, pers. comm..). This is particularly true during extended warm periods (summer and autumn), where it has been demonstrated that at temperatures more than ~20 °C, every increase by 1 – 2 °C may conceivably double DO consumption (Figure 13). A similar relationship has also been demonstrated for ammonium (N) fluxes. Above ~20 °C phosphate (P) fluxes are more closely related to sediment P concentrations.

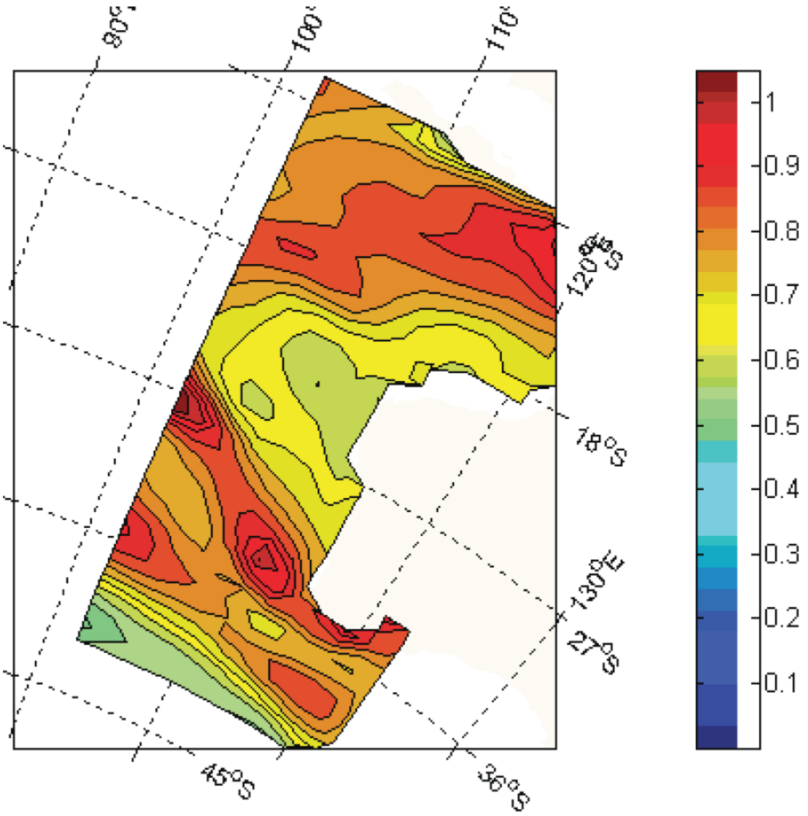

Figure 12 Predicted sea surface temperature change off Western Australia in 2061-2070 when compared to 1991 - 2000 under scenario *A2* Source: Durack (2002)

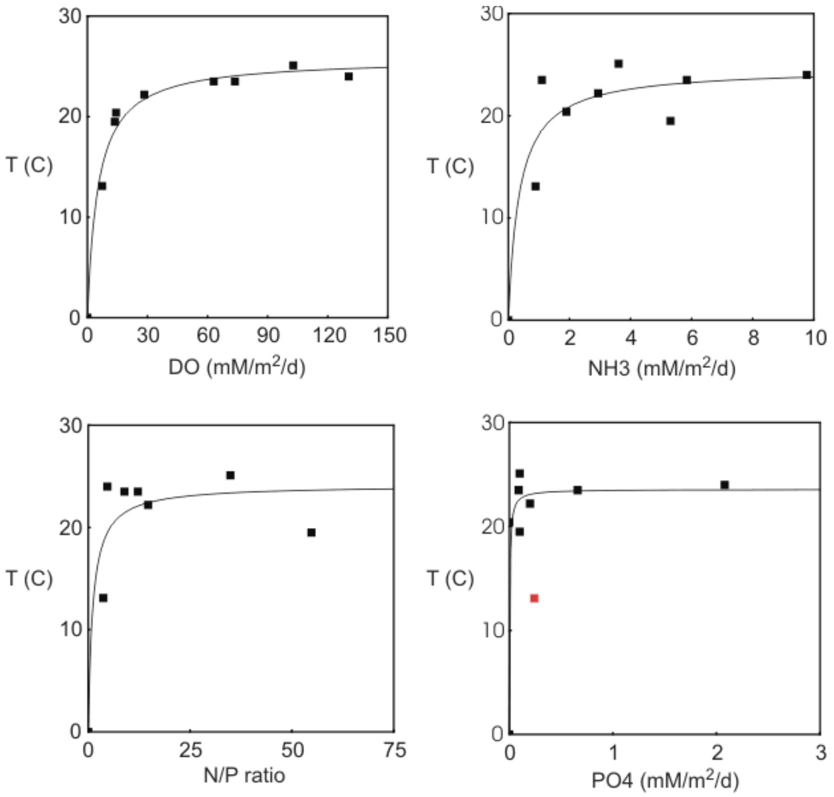

Figure 13 Relationship of temperature to oxygen consumption and nutrient fluxes (mM/m²/ day) from Swan Canning river system sediments (a) temperature versus dissolved oxygen consumption (b) temperature versus ammonium flux (c) temperature versus N/P ratio from sediments (d) temperature versus phosphate flux. *Data source*: Douglas (unpublished data)

1.6.4 Storm surges

Storm surge occurrences are difficult to project for the region due to the input of local and remotely forced motions. Surges depend on the severity and number of frontal systems impacting on the region in winter and also on the number and severity of weather systems crossing the coastline to the north of Fremantle. There is no information with regard to future changes to weather systems impacting on storm surges in Western Australia. Using the projected mean sea level rise, the extremes of sea level could be estimated as shown in Figure 14. The predicted values indicate that by 2030 (ca. 0.10 m sea level rise), the existing maximum recorded water level would be experienced every 20 years and by 2070 every one to two years (Figure 14).

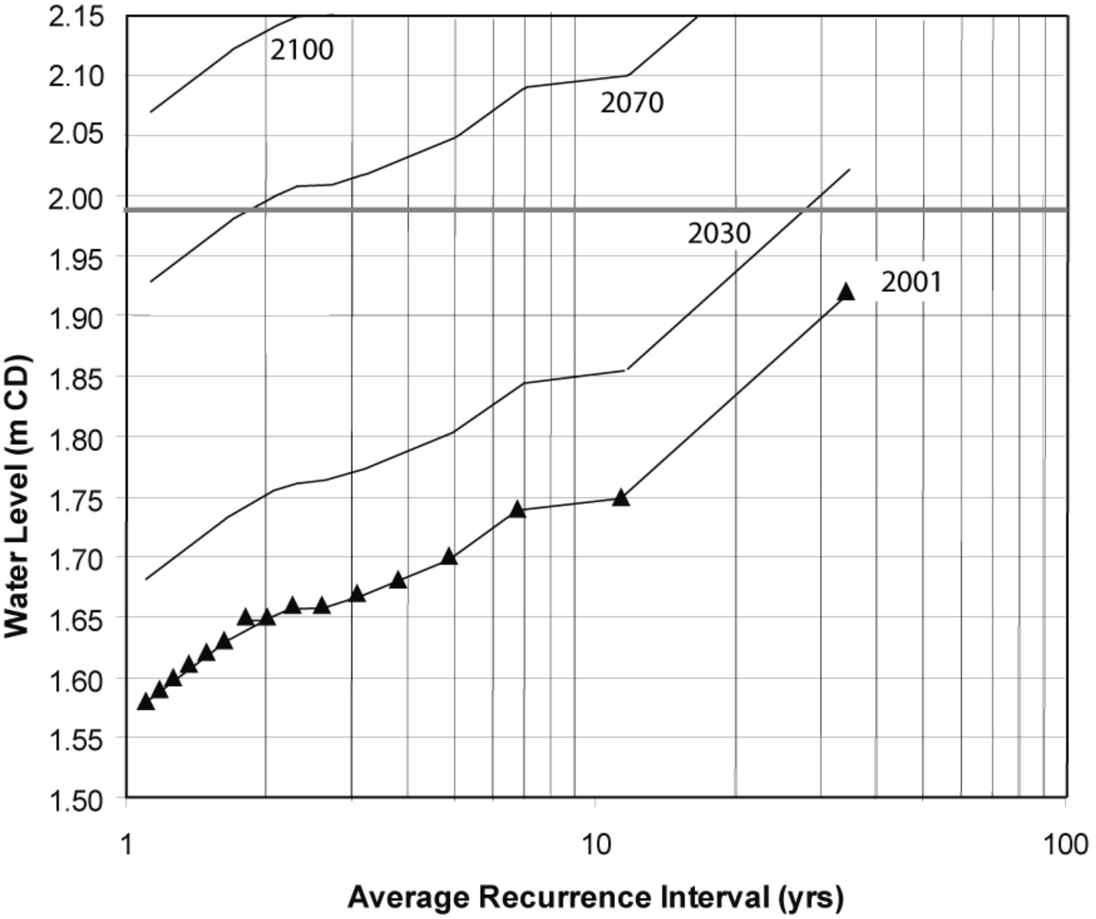

Figure 14 Predicted recurrence intervals for mean sea level rise of 0.10 metres (2030), 0.35 metres (2070) and 0.50 metres (2100) The highest water level recorded to date (1.98 metres) is shown for comparison. *Source:* Eliot and Pattiaratchi (*in preparation*)

1.6.5 Hydrodynamics and the salt wedge

Hydrodynamics of the estuary depend on streamflow, ocean water levels and the salinity (density) difference between the upper estuary and the ocean. Predicted changes in streamflow indicate the estuary is likely to experience mean salinity levels closer to oceanic levels if climate change continues unabated. Future upstream migration of the salt wedge is likely to be limited as it currently extends to the navigable reach of the upper estuary (West Swan Bridge). The major influence of predicted changes on the hydrodynamic regime is likely to be the reduction in streamflow, resulting in a higher salinity environment throughout the estuary and a reduction in vertical stratification in the absence of freshwater inflow.

1.6.6 Relative sea level rise

Future changes in sea level, particularly on a regional basis, are associated with a high degree of uncertainty. The rate of sea level rise is governed by many factors, the most important of which is the thermal expansion of the ocean due to warming. The lower bounds of sea level rise can be identified with relative confidence but there is a great deal of uncertainty associated with the risks of positive feedbacks causing accelerated change in ice cap movement and discharge.

This risk is reported in the CSIRO climate change paper (CSIRO 2007; p. 92). In addition, researchers have found that sea levels are tracking towards the upper trajectory of the IPCC's 2001 projections (Church 2007).

Regional oceanographic and meteorological effects and vertical land movements further compound the uncertainty about future relative sea level rise at any site. The projected relative sea level rise for the south west Western Australian region is presented in Table 12 for both the B1# and A2# scenarios. These values are presented as cumulative increases added to the total increase of 0.16 metres recorded since the beginning of the sea level measurements at Fremantle in 1897 (Figure 8).

Table 12 Projected relative sea level rise for south west region

Element	Scenario	Change relative to	2000	2030	2070	2100
Sea Level Rise - excluding future rapid dynamic change in ice flow*	**B1#**	1897	~0.16m	0.22m- 0.33m	0.28m- 0.43m	0.35m- 0.55m
	A2#				0.3m-	0.4m-
						0.5m- 0.7m
Sea Level Rise - including future rapid dynamic change in ice flow	**B1#**					0.6m- 0.9m
	A2#					

Interpolations between 1990 and 2100 are linear approximations.

1.6.7 Winter rainfall

As noted in section 1.4.3, in addition to a weakening of storm intensity and frequency, the later northward movement of the zone of cyclogenesis has affected the seasonal timing of rainfall during the 'winter' half of the year. Recent IOCI research is beginning to study these synoptic trends for application in model projections. However, quantitative scenario projections of 'winter' rainfall in this report are confined to a 'total winter rainfall' of May to October inclusive (i.e. inclusive of late autumn and early spring).

Attributions and projections of winter season rainfall and river flow are complex. The observed trends of these climate elements have been statistically unusual. However, although statistically unusual, the trends have not been outside the bounds of extremes, which could be explained by natural variability. The observed trends have also followed directional changes expected of anthropogenic global warming. Although there are good grounds for assuming that global anthropogenic climate change has altered the statistical expectation of present and future seasonal rainfall totals, the outcome in actual observations has exceeded median rates of change from ensemble runs of climate models

Climate modelling is consistent in projecting a sustained downward trend in the region's rainfall in this century due to increasing greenhouse gas (GHG) concentrations. However, only part of the observed rainfall decrease – 10 per cent of the total winter half – can be explained by modelling of GHG forcing. Typically, this 'explained' component is approximately one half the observational estimate (see IOCI 2005d). This leaves the following possibilities or mix of possibilities:

- part of the decrease may be natural variability, not change, and might not continue as a trend;
- modelling has underestimated the GHG induced change so far;
- land clearing has been a significant contributor to change; and
- other, yet unspecified, temporary or permanent forcing may also be involved (e.g. aerosols).

Statistical downscaling of global models has been carried out by Charles *et. al* (2004) to achieve regional resolution for rainfall scenarios. Scenarios presented here are based on those contained in unabridged reports of IOCI Stage 2 (Bates pers. comm.)[6] and associated studies applied to the Stirling Catchment (Berti *et al.* 2004).

The development of these scenarios has involved assumptions to reconcile with explained and unexplained components of pre-1990 changes. These assumptions and adjustments are detailed in Appendix 2. They seek to broadly represent the 50-percentile range of post-1990 ensembled runs for the A2# and B1# scenarios, as affected by alternative assumptions regarding anthropogenic factors, such as land clearing, on the actual climate outcomes realised at 1990.

The scenarios proposed for this study would represent a mid-range of projections amongst those reported from internationally available Global Climate Models. It is notable that emission scenario selection makes very little difference at 2030, with greatest variations occurring at 2100. The scenarios presented are nominally for the A2 and B1 SRES scenarios. These include adjustments as outlined above and are discussed further in Appendix 1.

Table 13 Projected mean winter rainfall decrease - south west

Element	Scenario	1990 as % decrease from 1925-75	Rainfall decrease as % change from 1925-75		
			2030	2070	2100
Total winter rain decrease from 1925-75	**B1#**	**10%***	7~14%	16~25%	17~27%
	A2#		12~20%	22~34%	26~40%
	scenario range		7~20%	16~34%	17~40%

Possibly not all GHG driven

1.6.8 Annual river flow

The non-linear relationship between rainfall and streamflow has magnified the impact of decreased rainfall on streamflows of the south west. This can be seen in the reduced total inflow into the reservoirs supplying Perth, where a 10 to 15 per cent reduction in rainfall since 1975 has contributed to an approximate 50 per cent decrease in total inflow from the long-term average and even larger decreases since 2001. Research in the Stirling Catchment has shown that for a future climate scenario, in which rainfall was decreased by 11 per cent, a 30 per cent decrease of annual stream flow could be expected (Berti *et. al*, 2004).

Studies to date have generally not incorporated the effects of further warming and potential evaporation increase in assessment of streamflow response. The Stirling Catchment studies however, did incorporate sensitivity studies, which suggest that a 10 per cent increase in potential evaporation coupled with the 11 per cent decrease in rainfall would lift the assessed potential streamflow decrease to more than 40 per cent. By 2070 potential evaporation increases of 2 to 7 per cent are indicated for the B1 and A2 scenarios respectively (CSIRO 2007).

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[6] The data are detailed in a draft Unabridged Report of IOCI Stage 2/Phase 2 (pers. comm Bryson Bates)

A portion of the current reduction in rainfall may be the result of natural multi-decadal variability. As discussed in the preceding section, this adds uncertainty to the rate of onset of further sustained rainfall and river flow reduction.

There is a limit to how far existing catchment models can project the impacts of future warming and drying scenarios. At some point the catchment vegetation will change sufficiently in response to stress and the model parameterisation could break down.

The scenarios presented in Table 14 are consistent with the rainfall scenarios. Table 14 is a merging of the 50-percentile ensemble range of the A2 and B1 model runs (CSIRO Mk3 and CCAM runs) (Draft Unabridged Report of IOCI Stage 2/Phase 2 - Bryson Bates pers. comm). The figures approximately represent the mid-67 per cent of model runs from the total ensemble range. Further explanation of the basis of the scenarios is presented in Appendix 2.

Table 14 Streamflow decrease from 1925 – 1975

Element	Scenario	1990 as % decrease from 1925-75	Flow decrease as % change from 1925-75		
			2030	2070	2100
Streamflow decrease from 1925-75	B1# - A2# scenario range	30%	22~55%	45~75%	50~80%

1.6.9 Extreme rainfall and flooding above the tidal zone

Modelling of future projected extreme rainfalls in the south west is of limited scope at this stage although recent modelling for national scenarios is notable (CSIRO 2007). As a consequence, only the qualitative expectations of Table 10 are incorporated in these scenarios (Table 15).

As a broad global trend, rising atmospheric temperatures imply that the atmosphere will have an increasing trend in moisture-carrying capacity. Most computer models therefore simulate a global trend of increasing extreme daily rainfall. This can occur even in the presence of an annual drying trend. However, a decrease is evident in winter rainfalls for south west of Western Australia at this time.

Table 15 Observed and projected (south western Australia/Swan Canning river system) trends in rainfall extremes and floods[7]

Phenomenon and direction of trend	Likelihood that the trend established or consolidated in late 20th century	Likelihood of a human contribution to observed trend	Likelihood of future trend under A2#/B1# scenarios
Decrease in frequency/ intensity of extreme winter rainfalls (1 to 10 year return period)	Likely	More likely than not	More likely than not
Increase/decrease in frequency/intensity of extreme summer rainfalls (1 to 10 year return period)	Small or non-existent statistically inconclusive	No clear evidence	No clear evidence for significant change
Decrease in frequency/intensity of winter flood flows (Swan tributaries)	**Extremely likely**	**Extremely likely**	**Likely**
Increase or decrease in frequency/intensity of summer flood flows (Swan tributaries)	**No clear evidence**	**No clear evidence**	**No clear evidence**

**Content in this table extracted from Table 9*

Winter extremes affecting flooding above the tidal zone

A decrease in winter rainfall has dominated the observed experience in the south west and there seems no justification for anticipating increased rainfall extremes in this region in the next few decades (B. Bates pers. comm[8] and IOCI 2005e). Indeed, recent modelling for national scenarios suggests that the observed decreases in the region's winter extremes will continue in the future (CSIRO 2007; page 74).

Under the B1# and A2# scenarios it would seem reasonable to expect that, in the mid-term, extreme winter rainfalls will not intensify beyond past experience and are more likely to reflect the post-1965 reductions. Given that the drying trends are commonly causing reductions in antecedent catchment wetness for most storm events and decreases in regional groundwater levels in uncleared catchments, the net consequence is a likelihood of a decrease in intensity and frequency of associated winter flooding.

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[7] In this report the IPCC Third Working Group judgement assessment terminology is used:

Likelihood as % probability of occurrence

Virtually certain	Extremely likely	Very likely	Likely	More likely than not
> 99%	> 95%	> 90%	> 66%	> 50%
	Extremely unlikely	Very unlikely	Unlikely	
	< 5%	< 10%	< 33%	

[8] The data are detailed in a draft Unabridged Report of IOCI Stage 2/Phase 2 (Bryson Bates pers. comm) .

- For the mid-term future the following two scenarios represent a reasonable range of probabilities.Rainfall intensities and flooding at various recurrence intervals continue at the lower intensity levels reflected in the statistics of the last 40 years with a tendency to further reductions in the future.
- Rainfall intensities at various recurrence intervals revert to higher (relative) levels and, as a precautionary conservatism in respect to designing to avoid flood damage, the longer term historical extreme rainfall and flood statistics are appropriate.

Summer extremes affecting flooding above the tidal zone

Modelling results in recently published national scenarios are notable (CSIRO 2007; page 74). These results do not suggest an increase of summer-half rainfall extremes, but rather hint at possible decrease. However, at the time of this study there is no strong observational or model evidence available to support any strong concerns or expectations for significant change, whether increase or decrease, in summer extremes of rainfall in the south west.

Under the B1# and A2# scenarios it would seem reasonable to expect that extreme summer rainfalls and associated flooding will not significantly increase or decrease in frequency or intensity.

1.7 Summary

This chapter has presented the latest scientific information on climate change and provided two scenarios for climate change in the Swan Canning river System. The scenarios indicate:

- accelerating atmosphere and ocean warming;
- decreasing in total winter stream flows;
- accelerating sea and tidal estuary level rise;
- drecreasing winter rainfall;
- increased frequency of droughts;
- increasing in extreme tidal estuary levels; and
- increasing frequency of warm spells and heat waves.

Chapter 3 applies this information to assess the impacts of climate change on the Swan and Canning rivers. Then, in Chapter 4, adaptation options and research priorities to ameliorate climate change impacts are discussed.

2 POTENTIAL CLIMATE CHANGE IMPACTS FOR SWAN AND CANNING RIVERS

Key climate changes anticipated at global and regional scales were outlined in Chapter 2 in conjunction with scenarios for climatic changes anticipated in the Swan and Canning rivers. In this chapter the scenarios are applied to determine the anticipated impacts of climate change. The chapter commences with a review of the impacts on the Avon Region as a whole as a contextual setting for specific effects in the Swan Canning river system discussed in subsequent sections.

2.1 Impacts on broader catchment (Avon)

Climate change predictions indicate a future reduction in rainfall for the south west of Western Australia. This decline in annual rainfall in tandem with the warming climate will act as the most significant drivers of change in the broader catchment. More specifically, the scenarios in Chapter 2 suggest that by 2030 there will be decrease in winter rainfall of between 7 and 20 per cent from that historically recorded between 1925 and 1975.

Any change in rainfall and annual runoff will influence sediment and nutrient loads in the catchment. Ali et al (2007) examined the rate of change in sediment and nutrient loads as a function of decline in rainfall. Their research estimates that a 10 per cent reduction in rainfall in the Avon River basin between 2004 and 2031 would result in a 35 per cent reduction in annual runoff (to 212 GL) and a 38 per cent reduction in annual salt loads (to 1634 kT) at Walyunga (Upper Swan). A 20 per cent reduction in rainfall during that period would reduce runoff by 60 per cent and salt loads by 64 per cent and a 30 per cent reduction will reduce runoff and salt loads by 80 per cent and 81 per cent respectively.

Rainfall decline will further add to the existing widespread drying of the catchments in the Darling Range and Avon river system. The continued drying of catchments may result in reduced annual sediment and nutrient and carbon loads. The possible extent of these impacts is hard to quantify due to major difficulties in estimating sediment and nutrient loads in flow events. Although flow monitors are adequate, sediments and nutrients are not discretely monitored in the catchment, with the exception of one station at Walyunga.

In summary, the timing and amount of water, sediment, nutrients, carbon and salt loads in the Avon Catchment will be altered by climate change through:

- reduction in rainfall and salt loads; and
- widespread drying of the catchment and consequent reduction in annual sediment, nutrient and carbon loads.

Reductions in rainfall will also have an impact on vegetation in the Avon region. Wet habitats (e.g. *Eucalyptus megacarpa* or bullich) are already decreasing, and may be lost completely if regional groundwater levels continue to fall below the invert of streams. Alternatively, the decline in rainfall has slowed the rate of spread of jarrah dieback (*Phytophthora cinnamomi*) as conditions for zoospore dispersal reduces. However any increase in episodic summer storms would result in a rapid expansion (Table 10).

Climate change has the potential to induce major changes in the reactivity of acid sulphate soils in the Swan Canning river system. Acid sulphate soils both underlay and fringe large portions of the estuary and are also present as laterally extensive, lenticular horizons in floodplain soils/sediments. In a scenario of increased erosion, exposure and desiccation of soils/sediments may lead to acid generation and the mobilization of both acidity and trace elements. In general, the non-limestone-bearing sediments of the Swan Coastal Plain are poorly buffered, and thus would have little inherent capacity to attenuate sulphide-generated acidity prior to groundwater or surface water discharge to the Swan Canning river system. Conversely, prolonged inundation during periods of increased water levels may increase waterlogging, reduce the rate and extent of oxygen infiltration and provide a transient barrier to the production of acidity via sulfide oxidation.

Agriculture is the predominant land use in the Avon Region. Increasing productivity on cereal farms is resulting in increased yields despite a decline in rainfall. However, if plant and economic thresholds are exceeded, changes to farm enterprises will result. A drier climate has been predicted to result in further expansion of grain growing in the wetter, western parts of the Avon Catchment (e.g. O'Conner *et al.* 2004) and a possible expansion of stock in the wheatbelt if drier seasons make cereals too risky to grow (John *et al.* 2005). Some perennials may be harder to establish as the climate dries. However, a shift to animal-based industries could encourage perennial fodder shrubs.

The key impacts of climate change in the broader catchment are summarised in Table 16:

Table 16 Anticipated future changes in the broader Avon Catchment

Area	Impact of Climate Change
Agriculture change	Drought and change in land practices
Water, sediment, nutrient, carbon and salt loads	Reduced rainfall, flow, sedimentation, nutrient load and salt load
Vegetation	Demarcation between jarrah-marri and wandoo woodlands is moving west Change in fire regime and groundwater recharge, water discharge and sedimentation Wet habitats decreasing or are being lost
Acid Sulphate Soils	Exposure of peaty soils in low buffering conditions which leach acid and mobilise heavy metals.

2.2 Impacts on Swan and Canning rivers

The impacts of climate change on the Swan and Canning rivers are discussed under the following headings: ecological impacts; impacts on infrastructure; human health and social impacts; and economic impacts. These subject areas are indicative of the priority management areas for the Swan River Trust.

2.2.1 Impacts on ecology

The ecological system of the Swan and Canning rivers is diverse and subsequently the impacts of climate change are numerous. Consequently, for ease of discussion, the impacts on ecology have been broken into a number of sub-sections, namely: sediment composition and nutrient loads; dissolved oxygen levels; nutrient cycling; fringing vegetation; community structure (including trophic dynamics with a particular focus on birds and fish); mudflats; sea grass and macro-algae; biodiversity; acidification; and geomorphology.

Sediment composition and nutrient loads

Anticipated reductions in rainfall and increased atmospheric and riverine temperatures will impact sediment retention and composition in the Swan Canning river system (as discussed above). Sediment composition is affected directly by the deposition of particulate nutrients, sediments and organic matter in river runoff, and indirectly by the efficiency of trapping of dissolved nutrients in river runoff by phytoplankton blooms – which subsequently deposit on the river bed.

During years of average to high runoff, particulate and dissolved nutrients (carbon, nitrogen, phosphorus) in river runoff are largely discharged to the ocean, with some retention of particulate nutrients (particularly carbon and phosphorus) in the middle and upper reaches and dissolved nutrients throughout the river system. In years of higher runoff the surface layer of nutrient-rich sediments in the middle and upper reaches may also be ‘scoured out’ and either (partially) redeposited or discharged to the ocean. In years of low runoff the particulate nutrient loads tend to settle in the middle and upper estuary rather than being flushed out, and there is also a high level of assimilation and cycling of dissolved nutrients by successive phytoplankton blooms.

The predicted reductions in river flows will consequently reduce loads of particulate and dissolved nutrients. However, reduced flows will also ensure higher proportions are retained. The eventual balance between these two processes is at present uncertain. Given retention is the predominant mechanism, it is expected that over time the total amount of particulate and dissolved nutrients in the Swan Canning river system will increase. Further, there may be an increase in the spatial extent of highly nutrient-rich sediments, as the reduction in river flows plus the extended tidal influence (due to sea level rise) may cause more efficient trapping of particulate nutrients via flocculation and transport of these sediment-laden plumes back into higher river reaches.

The degree of sediment retention and changes in sediment composition will also depend on the annual extent of the penetration of the salt wedge, the scale and nature of changes in urban runoff (due to urban expansion) and agricultural runoff (due to changes in type of agriculture) and episodic events such as large-scale bushfires. Changes in sediment composition will also depend on the degree of any change in groundwater nutrient inputs to the Swan Canning river system, which will presumably decrease, but any proposed drainage schemes – which largely intercept groundwater, and in particular shallow groundwater which is often enriched in nutrients – will also need consideration. The recent trend towards diverting stormwater and groundwater in urban drains into the Superficial Aquifer will reduce nutrients and freshwater inflows to the rivers.

Groundwater

A combination of decreased rainfall and runoff, with increased propagation of the saline wedge and riverine salinity, is likely to fundamentally influence the hydrology and ecology of the near-shore zone in the Swan Canning river system. Previous CSIRO research on the hydrology of the estuary has demonstrated seasonal inundation and displacement of the near-shore zone groundwater by saline waters, particularly on the inside of major meanders (Linderfelt and Turner 2001).

Increasing density within the saline wedge and its probable longer residence time in the mid to upper reaches due to decreased flushing, is likely to lead to enhanced penetration into the shallow aquifers surrounding the main Swan channel. The effects of this change in shallow groundwater composition and structure are likely to be many. In ecological terms, both animals and plants accustomed to more transient and lower salinity levels may not be suitably adapted to survive an increasingly saline shallow groundwater regime. Local residents who have historically abstracted shallow groundwater may find the increase in salinity renders their bores unusable.

Groundwater levels have fallen in Darling Range catchments as a result of lower rainfalls since the mid-1970s. This has been gradual and progressive such that levels are now below the invert of streams in many cases and unlikely to be fully recovered by a wet year or two, or a major storm. This means that runoff yields as a percentage of rainfall have progressively declined as catchments have dried (e.g. rainfall was average in 2005 in metropolitan catchments but runoff was only about a quarter of the long-term average).

Groundwater levels have also declined in the Superficial Aquifer on the Swan Coastal Plain resulting in the following changes.

- A loss of freshwater wetlands and groundwater dependent GDEs (suitable for waterfowl that use the rivers).
- Reduced baseflow into drains that intersect the water table (e.g. most main drains).

- A consequent reduction in nutrient loads from these drains (but not necessarily a reduction in nutrient concentrations).
- Land that was previously subject to inundation being made suitable for urban and industrial development.

Dissolved oxygen (DO) & nutrient cycling

Dissolved oxygen levels equate to the amount of free oxygen available in water. DO is required by fish and other aquatic organisms for respiration. Oxygen levels in the water column depend on the diffusion of oxygen to replace oxygen consumed by (i) microbial decomposition of organic matter (mainly in the sediments, but sometimes in the water column during the collapse of large phytoplankton blooms), and/or (ii) the combined respiration of large phytoplankton blooms and fauna during the night. The diffusion of oxygen across the water/air interface is generally low under quiescent conditions, and diffusion in the water column is greatly impeded by any stratification, making it difficult to ensure adequate DO levels in the river benthos. The Swan Canning river system is however, prone to local and regional discharge of groundwater in the margins and base of the channel, which may manifest as regions of low dissolved oxygen.

With increases in water temperature the amount of oxygen that can be held in the water will decline and bacterial respiration will increase. Overall, changes in the extent, frequency and severity of algal blooms are difficult to predict due to varying nutrient loads delivered by river runoff, groundwater and sediment nutrient-cycling processes. In addition, changes in water depth, water temperature and clarity also impact on algal bloom abundance, species composition and succession.

Irrespective of any changes in algal blooms, there is an increased potential (intensity, frequency, duration) for low DO events and more fish kills in the middle and upper estuary due to increased sediment oxygen demand, increased stratification, increased water depth and higher temperatures (warmer water can hold less oxygen than cooler water). Increased water temperatures can also be expected to increase sediment oxygen demand (Douglas, *unpublished data*). The spatial extent of these low DO events may retreat upstream, as the combination of reduced river flows and a rise in sea level (and therefore extended tidal influence) causes a change in the area of stratification.

For the purpose of this report, nutrient cycling is simplistically considered as:

1 Uptake of nutrients by plants and their incorporation into organic matter;

2 Release of nutrients from decomposing organic matter; and

3 Conversion of inorganic nutrients into forms unavailable for plant uptake.

Items one and two take place largely in the sediments, and in well-oxygenated waters. The natural processes involved in item three convert a proportion of nutrients into forms temporally unavailable for phytoplankton growth.

The natural processes for nutrient removal are reasonably effective in the lower estuary, but relatively poor (compared to many other estuaries in Australia) in the middle and upper reaches. As the marine influence extends upstream so will the key processes in both the N and P cycles. For example, rates for both N fixation and denitrification may change depending on species changes and carbon loading rates.

Nutrient cycling processes in the middle and upper estuary will be affected by the increases in sediment organic matter content, increased stratification due to a greater vertical salinity gradient, and extended periods of low DO levels that are predicted with climate change. The greater salinity gradient will also increase the water column stability and hence, reduce the occurrence of convective overturn and mixing further prolonging episodes and the spatial extent of low DO at the sediment-water interface. Lower DO levels at the sediment/water interface will further reduce the processes that convert nutrients into forms less available for plant growth. Consequently a greater proportion of nutrients in the organic matter accumulating in the sediments will subsequently become available (after microbial decomposition) to fuel further growth of phytoplankton and/or microphytobenthos in shallow areas. This will be exacerbated by increasing river water temperatures, which will increase nutrient flux from the sediments.

Reducing conditions associated with anoxia generally enhance the release of nutrients in sediments. Under appropriate growth conditions and with an initially non-limiting nutrient flux, this will facilitate an ongoing cycle of phytoplankton blooms, high sediment organic matter content and high sediment nutrient release, and reduced denitrification rates. High nutrient concentrations are likely to subsequently build up in bottom waters under stratified conditions.

In effect, lower nutrient inputs (from groundwater and catchment runoff) may perpetuate a similar level of phytoplankton blooms. High nutrient levels in bottom waters will tend to favour motile or buoyancy-regulating algal species (e.g. dinoflagellate or cyanobacteria blooms respectively, both species of which are potentially toxic), rather than the more ecologically beneficial groups of phytoplankton such as diatoms. Enhanced fluxes of some trace metals (e.g. iron, manganese, molybdenum) from sediments also occur under anoxic conditions, and some are known to induce toxicity in certain species of phytoplankton as well as nitrogen fixers such as some cyanobacteria.

Fringing vegetation

Fringing vegetation along the banks of the Swan Canning river system exist as vegetation ‘complexes’, each with a characteristic species composition. Different complexes occur with differing soil type, elevation (i.e. distance from the shore) and distance upstream. This is dependent on the level of inundation by tidal and/or flood water and water salinity. Groundwater expressions along the shores of an estuary can also affect zonation, particularly if the groundwater is of low salinity. Fringing vegetation communities are naturally dynamic and variable, but it can take decades for responses to changed conditions to become apparent.

The fringing vegetation has important physical and ecological functions for the river system. Roots of riparian vegetation support riverbanks and shade reduces water temperatures (most Western Australian freshwater fauna are cold stenotherms and are consequently intolerant of elevated water temperatures). Ecologically, carbon from riparian vegetation is important for consumers including aquatic invertebrates and fish.

At present, fringing vegetation along the estuarine reaches of the Swan Canning river system (where present) comprises – in order of increasing elevation and decreasing salinity - samphire salt marsh, Casuarina/Melaleuca forest and Melaleuca/Juncus (tree/sedge). Further upstream there is a transition from estuarine to freshwater vegetation typified by Eucalyptus/Melaleuca forest (often with Juncus at the river’s edge), and freshwater riparian vegetation such as Melaleuca swamp complex.

There are a number of anticipated impacts on fringing vegetation due to the changes in sea level and river runoff predicted to occur with climate change (Table 17). These impacts can be summarised as (i) change in vegetation distribution, (ii) change in vegetation density, and (iii) species invasion. The functional amount of fringing vegetation in the river is anticipated to remain the same providing there are suitable (i.e. undeveloped) areas for its landward extension to occur.

Table 17 Ecological impacts on fringing vegetation due to predicated increases in sea level and decreases in river runoff

Impact	Response
Increase in sea level rise Decrease in river runoff	Zones of saltmarsh, Casuarina/Melaleuca forest and Melaleuca/Juncus (tree/sedge) will retreat from the shore and extend their distribution landwards, and also extend their distribution further upstream.
Increase in sea level rise Decrease in river runoff	Transition vegetation will retreat from the shore and extend its distribution landwards. It will also retreat from its downstream extent but extend its distribution further upstream. Some areas of Eucalyptus/Melaleuca forest will be invaded by more salt tolerant species such as Casuarina, and may become Casuarina/Melaleuca forest (this has already happened in some parts of the Swan Canning).
Invasion by transition vegetation	The downstream extent of freshwater riparian vegetation will be reduced.
Invasion of dryland species at the landward edge Reduced groundwater flows may also contribute to this pattern.	Freshwater riparian vegetation will extend further into the (retreating) river bed, and the width of riparian vegetation may be reduced overall
Reduced runoff in the freshwater reaches of the river.	During transition in the fringing vegetation there is the potential for large areas of tree dieback or loss of tree health in areas of fringing vegetation.
Decrease in river runoff	The effective width of any vegetated zone along the freshwater reaches of the river will be retained, but will consist of more dryland species on the outer edge.

Community structure

Climate change is expected to result in a slightly larger and deeper lower estuary that has essentially marine conditions for most if not all of the year, with water quality similar to or possibly better than at present. In contrast, climate change is expected to result in reduced water quality, increased low DO events, more dinoflagellate blooms and possibly more fish kills in the middle and upper reaches.

The changes in community structure that are expected to occur are as follows.

In the lower estuary, there will be limited change in productivity and a possible slight increase in species diversity due to the recruitment and retention of more marine species of plankton, macroalgae, invertebrates and fish (see Trophic Dynamics in Detail – Birds and Fish). These changes in productivity are based on the assumption that the proportions of seagrass, mudflat and fringing vegetation habitats in the lower estuary do not change significantly.

In the middle and upper estuary productivity will be high, but there will be a reduction in the diversity of plankton, invertebrates and fish. Increased dominance by small, fecund and fast growing opportunistic species is likely. This is a classic symptom of nutrient enrichment (Pearson and Rosenberg 1978).

An extension of seagrasses into shallow water habitats may take place, as could the growth of free floating algal species such as *Gracilaria* and *Hincksia*, leading to changes in total habitat areas (see Seagrass and Macro-algae below).

Trophic dynamics

Trophic dynamics are determined by trophic structure, which in turn is determined by the number of trophic levels in existence. Trophic levels are amalgamations of species that have similar feeding habits (for example, plants, herbivores, and carnivores). Therefore, trophic dynamics refers to the feeding relationships of organisms in communities and ecosystems.

The typical estuarine food web is a complex interaction of food chains involving the following trophic groups:

- plants (phytoplankton, macroalgae, seagrasses, fringing vegetation);
- herbivores (zooplankton, some fish, ducks and swans);
- planktivores (small fish such as pilchard, sprat, hardyheads, anchovies);
- detritivores (benthic invertebrates, Perth herring, sea mullet);
- omnivores (benthic invertebrates, black bream, cobbler, yellow eye mullet, waders); and
- carnivores (mulloway, tailor, cormorants).

These trophic groups are represented in the lower estuary where major climate change impacts are not anticipated. In the middle and upper estuary the trophic groups are also represented at present, but by a reduced number of species. With the predicted decline in water quality and increased level of low DO events in the middle and upper estuary there is the potential for trophic dynamics to become even simpler (involving fewer species) with periods dominated by planktonic food webs due to loss of benthic invertebrates.

This loss in biodiversity may also cause a ’feedback loop’ that exacerbates the effects of nutrient enrichment as follows: fewer large predatory and omnivorous fish ==> increased abundance of small fish that eat zooplankton ==> decreased abundance of herbivorous zooplankton ==> increased abundance of phytoplankton. Depending on its spatial and temporal extent, this loss in biological diversity and trophic structure will result in an overall loss in the ‘resilience’ (i.e. ability to cope with change and recover afterwards) of the middle and upper Swan estuary.

Trophic dynamics in detail – birds and fish

A detailed review of the impacts of climate change may have on trophic elements of the Swan Canning river system is beyond the scope of this background report. Consequently, birds and fish have been selected as the key priority species due to their economic and social value.

Impacts on birds

The Swan and Canning rivers are of recognised importance for birds, both for birds that use the aquatic environments (waterbirds) and birds that use terrestrial environments (landbirds).

Higher water levels, leading to stronger tidal influences upstream, reduced freshwater inflow (reduced rainfall) and increased temperatures are the key climate change impacts that will affect birds in the Swan and Canning rivers. Further, the effects of increased water levels and tidal influences will be enhanced by the reduced freshwater inflow. These climatic variations will result in changes in salinity levels; sedimentation; nutrient levels; vegetation; trophic structure of marine species; and pH levels. Further, changes in development patterns surrounding the river, as a consequence of increased residential population and climate change, will impact Swan and Canning river birds.

The key impacts of climate change on birds in the river system are likely to be a:

- decline in the abundance of waders due to a loss of foraging habitat;
- potential increase in the abundance of swans and ducks;
- critical shortage of roosting areas for swans, ducks, cormorants and terns, especially in the lower estuary;
- shortage of freshwater sources for swans and ducks in the lower estuary;
- decline in freshwater wetlands in the upper reaches of the rivers, particularly of sites used as summer drought refuges;
- decline and fragmentation of fringing and adjacent vegetation, important in urban areas for landbirds; and
- possible threat from poor water quality in the mid to upper estuary.

Further information on the current spatial and temporal extent of waterbirds and landbirds in the Swan Canning river system, and the potential impacts of climate change on their abundance and distribution is provided in Appendix 5.

Impacts on fish communities and fishing

Climate change will impact fish species in differing ways depending on their trophic structure and life-cycle. Species comprising the fish community can be broadly grouped into the following life-cycle categories (Loneragan *et al.*1989).

- Marine stragglers – marine species that occasionally enter estuaries as adults usually when conditions are marine, or near marine (for example, school whiting, juvenile snapper, Australian herring).
- Marine opportunists – marine species that utilise the estuary extensively during some stage of their life (for example, as juveniles). Sea mullets, yelloweye mullets and tailor are good examples of marine opportunists. The blowfish is an extreme case with both juveniles and adults resident in the system for a large part of its life-cycle.
- Estuarine – estuarine species spend their whole life-cycle in the estuarine environment (for example, black bream).
- Anadromous – species that live in the sea but breed in the upper estuary. Perth herring is the only anadromous species in the Swan River.
- Freshwater – species confined to the freshwater regions of the estuarine system.

Harvested invertebrates such as cephalopods, crabs, prawns and mussels can similarly be grouped into the same life-cycle categories. The number of species in each category varies primarily as a function of the region of the system (for example, lower, middle and upper estuary), and to a lesser extent, season and year (Loneragan *et al.* 1989; Hoeksema and Potter 2006; Kanandjembo *et al*. 2001).

Physical changes in the Swan Canning river system as a result of climate change include reductions in, and changing patterns of, runoff and riverine discharge, increased tidal amplitude (storm surges) and elevated water temperatures. Fish are likely to respond directly through changing distribution and abundance, or indirectly via changes to their habitat and food supply; and may suffer lethal (fish kills), or sub-lethal effects. If the physical, chemical and microbial/food web characteristics are altered by climate change, there is the potential for changes in species composition, distribution and abundance throughout the river system.

Economically important species will respond to riverine changes and subsequently influence the recreational and commercial amenity currently provided by these species. Marine stragglers may become more abundant in the lower estuary, and penetrate further upstream than they have historically. This trend is already apparent, with species such as Australian herring, juvenile snapper, and squid now more consistently abundant in the lower estuary. Indeed, during recent years, catch and effort data from the few fishers that operate in the commercial fishery showed that an increasing proportion of their catch was comprised of marine stragglers. However, the extent to which the effects of ongoing climate change on this sector of the fishery will need to be managed will depend on whether or not the remaining two operators relinquish their licences through the Fisheries Adjustment Scheme.

Blowfish provide one of the best examples of the response of a marine opportunist to the changing patterns of runoff and riverine discharge. Historically, from time to time, conditions in the estuary have suited the recruitment, survival and growth of the progeny from successful marine spawnings. However, historically, periods of sustained winter riverine discharge are thought to have contributed to this species failing to become established as a major component of the estuarine fish fauna. During recent years the absence of significant periods of winter freshwater discharge has assisted blowfish to become established as a permanent and dominant component of the estuarine finfish community. The magnitude of its dominance means that it has managed to compete very successfully for food and shelter in the estuarine system at the expense of other species. Further, because it is a most undesirable species for anglers, its dominance has modified angler behaviour, such as discouraging participation, discouraging the use of bait in favour of lures, or encouraging fishing at night instead of during the day. This in turn has changed the size, and species composition of the recreational catch, and thus the nature of the amenity provided by the economically important fish community.

The key invertebrate marine opportunist, the blue swimmer crab, is the principal target species for the two remaining commercial operators. The persistence of more marine conditions for longer during the year, and further upstream, coupled with elevated water temperatures in the adjacent ocean where they release their young, should enhance recruitment of this species into the estuarine system. Further, provided water quality is adequate, growth and survival of the species will also be enhanced.

The preferred habitat for the true estuarine species appears to have extended further upstream, with less marked seasonal changes in distribution throughout the system. The period of reduced freshwater discharge during recent years seems to be well correlated with more consistently strong annual recruitment of black bream, the main economically important true estuarine finfish. It may also be correlated with a reduction in the quality of the important upstream habitat for the anadromous Perth herring, and freshwater habitats preferred by the few true freshwater species that still survive in the system.

Mudflats

As discussed, intertidal and shallow subtidal mudflats on the margins of the lower Swan Canning river system are an important habitat for benthic invertebrates and feeding area for fish and waterbirds – especially migratory waders. The main areas of importance are Alfred Cove/Waylen Point, Pelican Point and the South Perth foreshore. Other areas used include the mud flats between Heirisson Island and Redcliffe, and along the Canning River.

The sea level rise predicted with climate change will result in a landward migration of the intertidal zone and shallow subtidal zone in the lower estuary — provided there is undeveloped land to accommodate the predicted sea level rise (it is assumed that tidal amplitude will not change). Although the change in the total area of intertidal and shallow subtidal mudflats is not known at present, their productivity per unit area is not expected to decrease, as nutrient inputs should be sufficient to maintain the microphytobenthos production on which benthic invertebrates depend.

Because of a change in the dynamics of both vegetation (some species invading others retreating) and foreshore sediment dynamics from changing energy regimes it is difficult to predict the extent of habitat change over time.

Seagrass and macro-algae

The most common seagrass in the lower estuary is the small species *Halophila ovalis*, which is more tolerant of low salinities and low light supply (and therefore turbid waters) than other species (Hillman *et al.* 1995). Small beds of the less tolerant *Heterozostera tasmanica* occur just downstream of the Fremantle Harbour, where waters are clearer and more marine.

Climate change is expected to cause some changes favourable to seagrasses in the lower estuary, including a less extreme salinity range, maintenance of marine salinities for longer periods, and possibly improved water clarity. The expected rise in sea level may result in some loss of seagrass from the deeper edge of its depth range (typically water depths of 2.5 – 3 m) if water clarity does not improve. The landward edge of *Halophila* meadows will extend, providing there is undeveloped land to accommodate the predicted sea level rise. Seagrass may also extend further upstream, but the turbidity of Perth Water would need to improve dramatically to allow this to occur. An increase in the establishment of marine species of seagrass is also a possibility.

The distribution of macroalgae in the lower estuary is largely constrained by the availability of suitable hard substrate for them to attach to with the exception of the drift species *Gracilaria comosa*, which is more constrained by light availability. There is no significant macroalgal growth in the middle and upper estuary due to the water turbidity. Macroalgae and freshwater flowering plants are, however, important biota of the freshwater reaches of the Swan and Canning rivers, except in those reaches of the Canning River where turbidity is excessive due to dense phytoplankton blooms.

With the increased marine salinities and possible improvement in water clarity expected to occur with climate change, marine species of macro-algae may extend their distribution (spatially and temporally) in the lower Swan Canning estuary. The distribution of macro-algae and aquatic flowering plants in the freshwater reaches of the Swan and Canning rivers may, however, decline, as water quality in the freshwater reaches of the Swan and Canning rivers also declines.

Freshwater biodiversity

In the Canning River there has been an estimated 96 per cent reduction in catchment runoff (due to regulation for potable water supplies). Therefore, the freshwater reaches of the Canning River above Kent Street Weir provide some indication of the potential state of the freshwater reaches of the Swan River due to effects associated with climate change.

The upper Canning is thus a river in winter (albeit with greatly reduced flows), but essentially a freshwater pool, or a series of disconnected freshwater pools, from spring to autumn. These river pools are an important summer refuge for aquatic and terrestrial flora and fauna, but have reduced in size or been lost due to sedimentation and the reduced flow regime. Waters are stagnant and anoxic, with intense, often toxic algal blooms regularly recorded. As a result of these conditions, the diversity of freshwater invertebrates and fish in the freshwater reaches of the Canning River is low (Bunn & Davies 1990).

In the upper catchment there are a number of weirs on the Avon that may become increasingly important freshwater species refuges (see section 3.1).

Climate change is expected to reduce the downstream extent of the freshwater reaches of the Swan River (due to rising sea levels and reduced river flows). Reduced runoff in the upper reaches of the Swan River will be combined with increased retention of sediments and nutrients. These changes in the upper reaches of the Swan River will combine to:

- reduce the spatial extent of the freshwater reaches of the Swan River;
- increase the level of fragmentation of the freshwater reaches into disconnected river pools;
- reduce the depth and quality of water in the freshwater reaches (especially in the

pools); and

- result in a reduction in the biodiversity of flora and fauna in the freshwater habitat that remains.

The existing problems in the freshwater reaches of the Canning River will also be exacerbated by the reduction in the quantity and quality of runoff expected with climate change, unless this is offset by the restoration of environmental flows.

Acidification/buffering capacity

As the concentration of carbon dioxide (CO_2) in the earth's atmosphere increases, so does the level of CO_2 that the oceans absorb. When CO_2 dissolves in water it reacts with water to form carbonic acid (H_2CO_3), making waters more acidic. These changes in the surface waters of the ocean also result in release of carbonate ions from $CaCO_3$-supersaturated deeper waters. The calcium carbonate reacts with carbonic acid (produced from increased CO_2 absorption) and decreases the level of acidification produced. This natural process, called 'buffering', acts to continuously stabilise the pH of seawater unless the supply of carbonate is exhausted.

Furthermore, modelling of the extent to which ocean acidification will affect the carbonate saturation depth - and how changes to that depth will modify the capacity of seawater to buffer any increases in acid - suggests that the process will be very slow, and not fast enough to offset the rapid acidification from CO_2 absorption. Any acidification effects will be particularly noticeable in shallow waters, and potential implications are as follows.

Many marine organisms make shells or supporting plates out of $CaCO_3$ via the process called calcification. As water becomes more acidic, the calcification process is inhibited and the growth and/or survival of certain organisms could be affected. As many of these organisms are the basis of primary production, any change in their life-cycle has the potential to affect ecosystems.

The speciation of many important compounds depends on pH. The speciation of nutrients such as phosphate, silicate, iron and ammonia would all be affected in the range of pH decreases predicted with ocean acidification. Some of these will be beneficial - for example as pH decreases, the concentration of toxic ammonia (NH_3) would be lowered in preference to the ammonium species (NH_4^+). For others the effects are less clear – for example the ratio of soluble to insoluble iron may increase, reducing the growth limiting effect that low soluble iron concentrations have in some areas (on some species) and causing an increase in phytoplankton growth, or inducing toxicity in certain species of phytoplankton.

Biodiversity may be affected, as some species will be better suited to higher CO_2 and lower pH (e.g. the capacity of blood to carry oxygen can be reduced by high CO_2 levels, and highly active animals may be less favoured).

Geomorphology – bank stability

Changes in sea level, episodic flooding (in a diminishing flood plain), storm surge, sediment supply and vegetative control of banks, intertidal and wetland areas will lead to changes in 'foreshore' dynamics and potential readjustments to sedimentary processes, particularly in the shallow areas of the mid-Swan. As an example, increased bank erosion and the loss of riparian vegetation may occur, which will further destabilise riverbanks,. The resultant slumping could mobilise considerable supplies of sediments that usually aggregate in important aquatic habitats such as pools, or influence the depositional characteristics (stability) of foreshore, areas critical to seagrasses. Another possibility is a change in light characteristics due to increased mobilisation of sediments. These changes will be transitional, with scales of 10 to 50 years or longer, but may also be actively managed to reduce or influence the potential impacts.

Summary of climate change impacts on Swan Canning river ecology

The ecological consequences of key impacts due to climate change and the effects of these changes on the ecological resilience of biological communities have yet to be fully established. In addition, the associated social expectations that are carried by the community and managed on their behalf by the Trust must be considered. Clearly, many of the changes will sit outside the domain of opportunity for active management. For other changes, choices must be made; for example, erosion of public open space and consequent habitat migration verses foreshore protection and retention of open space. Cox (2006) demonstrates that not only are community perceptions strongly influenced by environmental quality, but so too is quality of life.

An understanding of social impacts will be key to the successful management of the Swan Canning river system in the face of increasing ecological uncertainty.

2.2.2 Human health and social impacts

Human health and social impacts are the key drivers behind management actions to address change in our environmental systems. Impacts can range from altered social practices and change in river aesthetics and recreational use, to economic impacts, alterations to fishing and tourism, and physical health related impacts such as increased risk of mosquito-borne diseases and skin irritations.

The descriptions of these health and social impacts and subsequent implementation strategies are more generalised than those arising from the physical and climate modelling. This is because there is a large number of potential factors that may impact on the community’s attitudes in future years and these may drive compensatory behaviours. For example, potential health effects may be modified by changes in community knowledge and awareness of potential hazards. Bank erosion may be affected by changes in tastes and even community acceptance of regulation of motorised boating. Community recreation patterns may be altered by acceptance of interventions in some reaches of the rivers to protect indigenous values and so on. Because of the uncertainty involved it will be important to develop an ongoing community engagement process to understand the drivers of adaptation and to manage them as far as possible to meet community and cultural aspirations. Reporting on the relatively fragmented data on current attitudes or behaviours in detail is of limited help in this regard.

River landscape and river bank management

The climate change scenarios presented in Chapter 2 indicate that sea levels will rise. Subsequently there may be a loss of ‘beach’ environment, ephemeral wetlands and associated vegetation. Under such scenarios, structures such as weirs and walled banks may be required to protect the river shores. Lesser stream flows and higher temperatures may also create a greater frequency of algal blooms, which may lead to a public perception of an unhealthy environment.

These physical changes will alter the aesthetics and landscape meaning landscape to a significant degree. The current iconic landscape representing the West Australian environment may become more ‘European ‘or ‘artificial’ in its appearance. Some of the landscape will be less visible because of reduced access to the foreshore and therefore less valuable to the community at large. The degree of change is, of course, a moot point and will depend on the visibility of changed management approaches.

Recreation and tourism amenity

The Swan River provides a major resource for active and passive recreation on the water and from its banks. Picnicking, walking, cycling, fishing and other activities occur on the banks. A multitude of boating activities, from sailing, rowing and kayaking to jet skiing and tourism boating, take place on the Swan River. Observations of the variety of bird species and iconic creatures such as dolphins are also popular pastimes. With or without climate change it is expected the demand for recreation and tourism from the Swan and Canning rivers will increase markedly in the long-term.

Climate change scenarios indicate that many of these activities may be negatively affected. Rise in water levels could exacerbate the problems currently encountered by some tourism operations in gaining access under the bridges. Access to the water itself may be affected by the diminution of ‘beaches’ and possible negative effects on jetties and infrastructure. Walking and cycling paths could be threatened. In terms of passive recreation, there may be a change in the biodiversity as the ephemeral parts of the wetlands become deepened and permanently covered.

Recreational fishing opportunities could be altered if ecosystem change has an impact on food availability or spawning environments. On the other hand there may be some benefits such as an increased presence of dolphins if the saline areas are more prevalent further up the rivers.

Finally, the development of weirs or other structures to cope with storm surges may also restrict some access.

Environmental and human health risk

The rising water levels, changes in salinity, and possible increases in temperature and perhaps greater nutrient levels causing algal blooms have the potential to exacerbate health threats. For example, increases in temperature and generation of acid sulphate acidity will have the potential to increase the mobility of many toxic substances in the water. The population of mosquitoes tolerant to warm and somewhat saline conditions may increase and fish may become unacceptable for human consumption. Further, the effects of climate change could exacerbate the health risks associated with water contact, such as minor and major infection.

Cultural and Indigenous issues

While the impacts on the landscape and environment can alter the meaning of the rivers’ environment, the change in water quality, environmental health and the inundation of open space can also have deeper cultural implications. George Seddon’s iconic publication regarding the Swan River ‘A Sense of Place’ (1972) clearly indicates the importance of the rivers to community identity.

This is currently being reinforced by the interpretive information provided in artificial wetlands designed for improving water quality. Such attempts to create stewardship will also underpin a changing but long-term attachment by the wider Western Australian community.

Inundation and changes in salinity also have the potential to threaten any relics associated with sacred sites near the river from the Nyungah community’s perspective.

2.2.3 Impacts on infrastructure

The major forms of infrastructure constructed around the perimeter of the Swan Canning estuary include: seawalls, bridges, roads, railway, pathways, stormwater drains, jetties and marinas. There is also significant natural infrastructure that includes reefs, cliffs and minor tributaries. The estuary experiences only limited tidal amplitude and consequently much of this infrastructure is only marginally higher than current water levels at high tide. The effects of climate change on established infrastructure can be broadly considered, recognising that climate change may bring about the following alterations to the system:

- increase in long-term water levels;
- increase in storminess leading to greater magnitude and frequency of storm surge.

The resulting impacts on infrastructure include:

- increased erosion of foreshore features such as sand beaches and low-lying dunes;
- increased erosion and damage of protective walls such as those along Mounts Bay Road;
- increased frequency of inundation of low lying features such as parks, roads, footpaths, and stormwater drainage systems; and
- some increase in damage to piers and abutments used for jetties and bridges.

Increased erosive capacity through elevated sea levels is a key issue for management. Accordingly the Swan River Trust commissioned an engineering assessment to determine the potential impacts of climate change on the Swan and Canning rivers. The engineering assessment was limited to the following types of marine infrastructure: jetties, seawalls, revetments, boat pens, boat ramps and groynes.

Drainage structures and development levels were not included in the assessment. However, as mentioned above, these are important components of the Swan River infrastructure and it is possible that those items may be more significantly affected by the anticipated impacts of climate change than the marine infrastructure.

The issue of drainage and flood control can be quite complex and is very site specific. Detailed discussion of drainage and flood control is beyond the scope of this background paper. However, the key issues are: river flood levels, existing development levels along the shoreline, drainage infrastructure and the use of the land that could potentially flood more frequently.

The impact of climate on infrastructure is a function of the physical setting, design criteria and design life. These issues are discussed in turn to illustrate the key impacts of climate change on infrastructure in the Swan and Canning rivers.

Physical setting

The physical setting on the Swan and Canning rivers has influenced the design of the existing marine infrastructure such as jetties, boat pens, seawalls and boat ramps.

In the lower reaches of the river system the water level regimes are dominated by ocean water levels, whereas upstream of the Causeway and Canning Bridge catchment runoff dominates the extreme water levels. The normal summer tidal levels greatly influence the design of jetties and pens with fixed decks as well as seawalls and revetments. In areas downstream of the Causeway and Canning Bridge, deck levels and seawall crests are often designed in the range of 1.0 m to 1.7 m above the Australian Height Datum. This datum is roughly mean sea level. These deck and crest levels are built at reasonably low levels because of functional requirements, and aesthetics, during low tidal levels in summer and autumn. Consequently, such structures are often inundated or experience significant overtopping during storm events.

The following photograph from The West Australian newspaper on 13 July 1995 shows a seawall along the Kwinana Freeway and an indication of the overtopping experienced during high water level events accompanied by strong winds and waves. The high river water levels were caused by the combination of storm surge and high tides. This occurs to some extent during most winters.

Wave conditions depend upon wind speed, direction, duration, and fetch distance (the length of water that the wind is acting over). Consequently, in the narrow reaches of the rivers the wind waves tend to be quite small, generally smaller than waves generated by boat wash, which can be in the order of 0.3 m to 0.6 m in height. The open areas of Perth and Melville Waters have significant fetches and waves can be 0.5 m to 1 m in height, with extreme events causing waves greater than 1 m. The wave conditions affect the siting, function and structural design of marine infrastructure along the rivers.

Figure 15 – Waves overtopping a seawall along the Kwinana Freeway during a winter storm in 1995 *Source*: The West Australian newspaper (13 July 1995)

Design criteria and design life

The climate change scenarios presented in Chapter 2 are summarised as physical factors that can impact infrastructure and are presented in Table 18 against the service life of the common marine infrastructure existing in the river. The service life of marine infrastructure is variable due to different standards for different structures. For example, a private jetty for a small boat may be constructed from untreated timber and have an effective service life of only 10 years. The major public jetties at Barrack Square and South Perth have been built to more demanding standards. Provided they are reasonably maintained, these jetties should last between 30 and 50 years.

Various types of revetments and seawalls have been built along the rivers and range from Gabion Baskets to limestone block walls. The former are likely to have an effective service life of five to 20 years due to the durability of the wire baskets (CIRIA no date). Alternatively, well-designed and regularly maintained limestone block walls have a service life of 30 to 50 years (service life may be reduced when located in proximity to acid sulphate soils).

Table 18 Physical factors effecting marine infrastructure

Item	Service life	Water levels *	Winds +	Waves Φ	Currents δ	Sedimentation φ
Jetties & boat pens	10 to 50 years	Deck levels, heights of chaffers & locating piles, & frequency of inundation	Berthing & mooring, & structural loads from moored vessel	Berthing & mooring conditions, & structural loads	Layout, & structural loads	Location, toe scour, maintenance of water depth
Seawalls & revetments	5 to 50 years	Crest levels, frequency & level of overtopping	Secondary effect on extent overtopping	Crest levels, frequency & level of overtopping, toe scour, & structural loads	Toe scour	Toe scour
Groynes	50 years	Crest levels, frequency & level of overtopping	Secondary effect on extent of overtopping	Crest levels, frequency & level of overtopping, toe scour, & structural loads	Toe scour, & effectiveness at sand trapping	Effectiveness at sand trapping
Boat ramps	25 to 50 years	Level of top of ramp	Siting for function	Siting for function, toe scour, & structural loads	Toe scour	Toe scour, & maintenance of water depth

*tides, storm surges and river floods; +prevailing winds, and extreme storm winds; Φ locally generated prevailing and extreme waves; δ river flows, tides, storm surges, and wind; φ erosion and accretion

2.2.4 Economic impacts

This section discusses economic impacts of climate change on the ecology, infrastructure, and social systems of the Swan and Canning rivers. As in section 2.2.2, the descriptions of the economic impacts and subsequent implementation strategies are more generalised than those arising from the physical and climate modelling.

Ecological economics

Increased soil erosion following drought, lower flows and higher water temperatures have negative implications for water quality. This may lead to increased eutrophication and algal blooms (Pittock 2003). Reduced runoff, higher riverine, estuarine and coastal aquifer salinity, and increased algal blooms could exacerbate water supply and water quality problems, particularly in Perth urban drinking water catchment areas (Pittock 2003). Furthermore, declining water quality reduces aesthetic value and consequently, property values may decrease. Given hedonic pricing, these economic impacts may be the highest, especially if recreational use is reduced. For example, rotting seaweed reduced the aesthetic and property values of areas surrounding the Peel Harvey Estuary in the 1970s and 1980s. Reduced water quality has already necessitated considerable investment in a range of remedial projects at the catchment and localised levels. There are increasing costs associated with intervention programs and monitoring programs that could be exacerbated by climate change.

Human and social economics

The primary result of rising salinity on recreational use of the Swan and Canning rivers may be increased fish kills. A decrease in fish will result in a reduction in the recreational amenity value for recreational fishers. Subsequently the businesses reliant on recreational fishing may have to shift to other locations or alter their business strategy. Both of these options would add to their operational costs.

Increases in algal blooms can restrict certain recreational activities such as windsurfing, kite surfing and swimming. A decline in recreational use will impact businesses that rely on recreational activities, such as wind surf hire or riverside cafes. Further, increased algal blooms, which reduce use of the rivers, may result in movement of people to alternative recreational sites such as the beach. This can cause overcrowding and traffic congestion.

Deoxygenation and algal blooms can result in fish death and high levels of toxins in fish. Consuming fish from the rivers with high toxic levels may have an impact on human health, and consequently those affected may try to seek compensation. Warnings of the dangers of eating fish may be necessary to prevent litigation issues.

Increased risks of bushfire will affect insurance premiums on properties that are at high risk. Insurance costs may become higher while the sales value of the property may decrease. Subsequently, communities may place pressure on local councils to increase the number of controlled burns or create fire buffer zones.

Subject to acceptable water quality in the rivers, hotter days may mean more people will go to the rivers for water activities. This can result in overcrowding and disutility (lower level of enjoyment).

The food sector may also be negatively impacted if agricultural activities in the catchment become less productive. Reduced supply of food from the catchment area may impose higher prices due to demand exceeding supply.

Infrastructure economics

Sudden storm surges will affect roads, cars and traffic conditions. Economic loss from traffic delays, road surface damage and car breakdowns is expected to rise. Permanent inundation will have an impact on private and public infrastructure such as river front properties, roads, parks and walking trails.

Perth riverside suburbs are selling at around $10 million and executive apartments with river views are selling for $2-3 million (Gibson 2007). High economic costs to foreshore and residential assets from inundation are expected and either mitigation or modification measures are required to prevent the inundation from occurring or to adapt to the inevitable inundation, respectively. The increased risk of exposure to extreme events has strong implications for the insurance industry, with higher premiums possible for clients, insurers and re-insurers (Pittock 2003). Loss of recreational areas such as riverside parks due to inundation can also have an impact on the quality of life for those living in the Perth metropolitan area.

Climate change introduces uncertainties in streamflow, water demand, population trends and land use changes. Dry soil conditions increase the risk of drainage pipe failure and collapse, whilst higher peak flows increase the risk of damage to storm water infrastructure (Howe et al., 2005). Further, stormwater infrastructure, dams, weirs, and river banks may need to be rechecked, repaired, and reconstructed to better deal with uncertainties in levels of rainfall.

2.3 Summary

The potential impacts of climate change on the Swan and Canning rivers and the broader Avon Catchment have been outlined in this chapter. The impacts have followed the scenarios of projected change developed in Chapter 2.

Impacts discussed range from those associated with ecological and human health, to those affecting the local economy. These impacts are summarised in Tables 18 to 22 as part of a discussion of potential options for adaptation.

The following chapter suggests the key strategies and adaptation priorities required to ameliorate the impacts of climate change.

3 Adaptation to the impacts of climate change

Climate change adaptation is defined by the IPCC (2001) as ‘adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts.’ In this report, the term adaptation is applied to mean an adjustment (whether passive, reactive or anticipatory; with a focus on anticipatory) that is proposed as a means of reducing anticipated adverse consequences expected from climate change.

To determine adaptation strategies, detailed information on underlying current and historic processes is required to highlight trends to estimate responses to climate change and to assess the implications of management decisions. Some system variables may be outside the range of past experience so any predictive model may be inaccurate. Consequently, a number of the adaptation strategies outlined below focus on the preliminary assessment of current conditions and underlying processes so future decisions can be based on the best available knowledge (otherwise known as anticipatory adaptation).

It is also important to note that the social and ecological environments of the Swan and Canning rivers are already experiencing change driven by climate and other pressures (notably pollution pressures). As such, an adaptive management approach is required to ensure that as information comes to light, management practices can be adjusted accordingly.

The adaptation priorities outlined below are the preliminary baseline adaptation decisions that can be, and should be, made now as a first pass to mitigate the impact of climate change on the Swan and Canning rivers.

In each subsection below, summary tables outline adaptation strategies and research priorities. They rank the likelihood of impacts, state the types of adverse impacts due to climate change, and rank the level of impact that these will have on the Swan River Trust’s strategic plans. The likelihood rating refers to the potential for adverse impacts to occur in the short term (less than 30 years). The ‘adverse impact rating’ can be inferred to determine management priorities. The risk rating relates to the level of impact climate change will have on the Swan River Trust’s strategic plans.

3.1 Strategies to inform adaptation to climate change impacts in the broader catchment (Avon)

Climate change impacts requiring adaptation in the broader catchment include: reduced rainfall amounts (and potentially intensities in both winter and summer) (Brian Sadler, pers. comm.), lower groundwater levels, reduced runoff, reduced sedimentation (unless vegetation cover is lost), and reduced nutrient and salt loads.

Management of the impacts of storms requires analysis of past flows from the Avon and coastal catchments to determine which events have caused problems in the past and whether there is a recent trend. A strategic monitoring network for flows, sediments and nutrients is a priority for the Avon Catchment. This will subsequently act as a basis to move to more cost effective management measures in the future. In addition, the overall predicted reduction in annual flows, including that arising from increased stormwater diversion to aquifers, needs to be analysed to determine if it will have a negative or positive impact on the estuary, especially in the river reaches.

Any changes in agricultural activities in response to a changed climatic regime require monitoring. For example, the mix of cropping and grazing may impact on erosion and runoff of sediment, organic material and nutrients. There remains strong interest by some landholders to increase saline drainage to the Avon River.

Spatial and temporal changes in vegetation should be monitored to ensure successful adaptation to changes in vegetation. Regional vegetation can be monitored using Landsat TM (Land Monitoring project, Landgate). Additional analysis of historic Landsat TM images to detect long-term change in vegetation conditions in the Darling Ranges will be carried out by Dr Eddy Campbell at CSIRO as part of a Premier's Water Foundation project.

In addition to regional monitoring, action should be taken to maintain priority areas. For example, riparian zones must remain vegetated to reduce the likelihood of erosion and sedimentation. The Avon and Swan Catchment Councils will complete implementation of, and annual review of, River Action Plans. The Upper Swan riparian zones can be monitored through analysis of annual digital aerial photography under the Urban Monitor project managed by CSIRO and Landgate.

In order to adapt to potential increases in Acid Sulphate Soils (ASS) we need to comprehensively understand the mechanism of ASS formation on the Swan Coastal Plain. Current management is based on eastern states experiences. The formation of ASS in Western Australia may differ, and therefore research is required to understand local processes and management options.

Research is also required to assess the risk of ASS that may occur after falls in regional groundwater levels and exposure of peaty soils to oxidation. Raising the discharge outlet level of drains may reduce the risk of over-drainage and also increase groundwater retention in areas with a high water table. This approach should be considered if increased groundwater levels are desired.

The adaptation and research priorities for the broader catchment are detailed in Table 19.

Table 19 Climate change impacts, adaptation strategies and risk rating for the broader Avon Catchment

Area/Issue	Likelihood	Adverse Impact of CC	Adaptation/Mitigation	Risk
Agricultural industry change	Low - medium	Amount and intensity of cropping and grazing may change	Monitor land use and land practices (e.g. drainage for salinity). Establish/maintain vegetative buffers between agriculture and rivering systems to reduce erosion, sediment and nutrients in the streams.	Low - medium
Water, sediment, nutrient, carbon and salt loads	High – largely beneficial	Reduced rainfall, flows, sedimentation, nutrient load and salt loads	Assess historic flows and sediment loads as a basis for cost effective management Establish strategic monitoring network for flows, sediments and nutrients in Avon Catchment	Low - medium
Vegetation type and condition	High	Thinning of forest areas and changes in communities (xeric)	Monitor regional vegetation with Land Monitor (Landsat ™) Ensure riparian zones are vegetated to reduce erosion and sedimentation.	Low
	High	Change in fire regime (longer season; reduced fuel loads)	Adapt fuel burning program	Medium
	High	Less groundwater recharge and discharge resulting in wet habitats decreasing	Ensure riparian zones remain vegetated to reduce erosion and sedimentation Monitor upper Swan riparian zones using digital aerial photography techniques	Medium
Acid sulphate soils	Unknown at present – possibly medium	Exposure of peaty soils in low buffering soils to conditions that will release acid and mobilise heavy metals.	Research of ASS formation on Swan Coastal Plain Assess risks associated with a falling water table Divert stormwater and possibly treated wastewater into the superficial aquifer	Medium

3.2 Strategies to inform adaptation to climate change impacts in the Swan and Canning rivers

3.2.1 Adapting to impacts on ecology

The key impacts on the ecology of the Swan and Canning rivers are driven by: rise in sea level; increased salinity in lower reaches of the system; increased periods of stratification; reduced flushing; and issues of water clarity. Once again, the development of management strategies requires a detailed understanding of historic conditions to determine trends in the system. Much of the adaptive strategies for the ecological system rely on setting research and management priorities. Table 20 lists impacts and adaptation strategies for the ecological system, and ranks the priority of the impact against the Trust's strategic plans. Each of these adaptation strategies is discussed in more detail below.

Adapting to changes in sediment retention and differing composition requires information on historical sediment loads and historical summer and autumn winter flows. Further, predictions of changes in nutrient loads (runoff and groundwater) due to projected urban expansion and probable changes in type of agriculture – with and without management, should be developed. It is not presently known which is the greater threat – diffuse loads from land-based sources through poor catchment management practice (which can be managed) or climate change.

In order to adapt to decreases in dissolved oxygen levels, critical habitats for key species of fish and crustaceans in the Swan Canning river system (typically riverine pools) in each season should be mapped and overlayed with predicted areas of low DO events. This information will enable the Trust to determine where best to apply intervention techniques (oxygenation, nutrient intervention) in the short-term. This short-term priority can proceed whilst longer-term measures to reduce nutrient inputs are being implemented.

In addition, an improvement in our understanding of the extent, severity and ecological significance of the low oxygen 'plug' of water that is present below the Narrows Bridge each spring and that subsequently migrates upstream with the salt wedge is required. The relative importance of this water versus in situ sediment oxygen demand in determining low DO events should be used to determine where best to apply intervention techniques (oxygenation, nutrient intervention) in the short-term. Finally, the relative importance of toxic algal blooms, low DO waters and 'habitat squeeze' (trapping of fish between areas with low oxygen and/or toxic algal blooms) in causing fish kills need to be clarified.

Changes in nutrient cycling have significant implications for trophic dynamics – especially algal growth. The magnitude of various nutrient sources (retention and recycling of nutrients from catchment runoff, groundwater inputs, existing sediment nutrient stores) in the Swan Canning river system is reasonably well documented. It is, however, not clear to what degree algal growth is fuelled by each source in each season – or even whether any one of these three sources is sufficient to fuel the present levels of phytoplankton growth because nutrients are in oversupply and growth is light limited.

Knowledge of the relative importance of each nutrient source, the nature and rates of key recycling processes, temperature changes (which may favour different species of phytoplankton) and changes in light regimes (quality and quantity) in each season is required to adapt to changes in nutrient cycling. Understanding the relative impact of climate change on nutrient cycling will enable management to be focused accordingly.

The impacts of climate change on fringing vegetation are described in Chapter 3 as alteration in type, density and distribution. To develop adaptation and management strategies, important areas of fringing vegetation need to be identified, mapped, monitored and risk-based management strategies developed with relevant stakeholders.

Further, assessment of the ecological importance of carbon from riparian vegetation for aquatic consumers (stable isotope analyses) needs to be undertaken and used to assess impacts on species shifts and nutrient cycles. The reserves adjacent to important areas of fringing vegetation need to be assessed to see if they will allow the expected landward migration of fringing vegetation. Furthermore, planning of development adjacent to the rivers will need to consider any expected landward migration of fringing vegetation. Finally, changes in vegetation need to be monitored and factored into foreshore protection strategies

Area / issue	Likelihood	Adverse impact of climate change	Mitigation and adaptation	Risk rating
Sediment accumulation	Low	Lower flow High trapping in estuarine basin Increase of nutrient rich sediments Low scouring in middle and upper estuary Low export to ocean	Develop models to predict changes in nutrient load due to urban growth and agriculture, with and without management Develop management strategies to capture sediment before it enters the estuary	Low - medium (reducing)
Greater biological oxygen demand (BOD) Low dissolved oxygen (DO)	High	Higher nutrient rich sediment retention in mid and upper estuary Higher water temperature will decrease O2 saturation and increase bacterial BOD Salinity stratification expected for longer periods and further upstream than at present Extended spatial and temporal low O2 will increase potential for fish death	Map areas of critical habitat for key species in each season to determine likely impacts and best areas to implement intervention techniques Develop better understanding of extent, severity and ecological significance of the low O2 plug, which annually migrates up the estuary in spring and down the estuary in winter Determine the role of the low O2 plug vs. in situ sediment O2 demand and how to best apply intervention techniques Use of intervention techniques such as oxygenation and modified clays.	High
Nutrient cycling	Medium - high	Key processes in the N and P cycles will move upstream Rate of N fixation and denitrification may change depending on species change and carbon loading rates Increased stratification and extended periods of low dissolved oxygen levels Fuel for further growth of phytoplankton	Knowledge of the relative importance of each nutrient source, the nature and rates of key recycling processes, temperature changes and changes in light regimes in each season is required to understand the relative impact of climate change - and focus management accordingly. Use of intervention techniques such as oxygenation and modified clays.	High

Area / issue	Likelihood	Adverse impact of climate change	Mitigation and adaptation	Risk rating
Riparian vegetation (loss / change)	Medium	Zones of saltmarsh will retreat and extend their distribution landwards, and also further upstream Transition vegetation will retreat from the shore and extend its distribution landwards Downstream extent of freshwater riparian vegetation will be reduced due to invasion by transition vegetation	Identify important areas of fringing vegetation and develop risk based management strategies Assess ecological importance of carbon from riparian vegetation for aquatic consumers (stable isotope analyses) to assess impacts on species shifts and nutrient cycles. Assess reserves adjacent to important areas of fringing vegetation to determine landward migration Development adjacent to the river will need to consider any expected landward migration of fringing vegetation Factor changes in vegetation into foreshore protection strategies and statutory planning	Low-medium
Marine community structure	High	More marine species that enter the estuary as juveniles Possible establishment of some tropical species Reduction in diversity of plankton, invertebrates and fish Increased dominance of opportunistic species	Develop ecological resilience models to predict the effects of water quality changes (particularly salinity and dissolved oxygen) from the lower to upper estuary. This will assist the prediction of the spatial patterns of community structure Continue long-term catchment management to reduce nutrient loads	*High
Trophic dynamics	High	Potential for trophic dynamics to become simpler with periods dominated by planktonic food webs due to loss of benthic invertebrates Increased nutrient enrichment	Develop ecological resilience models to predict water quality (particularly salinity, temperature and dissolved oxygen) in the upper estuary to assist the prediction of the spatial patterns of community structure Continue long-term catchment management to reduce nutrient loads	*High

Area / issue	Likelihood	Adverse impact of climate change	Mitigation and adaptation	Risk rating
Birds	Low – high (species specific)	A decline in the abundance of waders due to a loss of foraging habitat Potential increase in the abundance of swans and ducks A critical shortage of roosting areas and freshwater sources Decline and fragmentation of fringing vegetation and increases in poor water quality	Where possible, allow tidal habitats to shift landward (see ‘Mudflats’ below) Create sandbars Reduce disturbance at shoreline roosting sites Supplement freshwater in lower estuary Revegetate fringing environments with plants able to cope with changed conditions	*Medium
Fish	High	Direct response to climate change impacts through changing distribution and abundance Indirect response via changes to their habitat and food supply	Develop models to assess how fisheries and their supporting ecosystems may respond to changes in the environment and to different management actions. Consider how the composition of each of the life-cycle categories, and recreational and commercial fishing amenity, might change Incorporate this knowledge into WAMSI Node 4, Project 4.3 to enable the development of more precise predictions	*High
Seagrass and macro-algae	High (gradual)	Less extreme salinity regime is favourable to seagrass Rise in sea level may result in some loss of sea grass Establishment of marine sea grass species Decline in freshwater macro-algae and aquatic flowering plants	Assess impacts of CC on water clarity Map distribution of macrophytes Predict sea grass distribution with change in sea level to ensure no decrease in distribution Assess reserves to determine the extent to which landward extension of seagrass is possible Development should accommodate landward extension of seagrass Continue long-term catchment management to reduce nutrient loads	Medium

Area / issue	Likelihood	Adverse impact of climate change	Mitigation and adaptation	Risk rating
Freshwater biodiversity	High	Reduction in downstream extent of freshwater reaches Reduced runoff in upper reaches and increased retention of sediments and nutrients Increased fragmentation of the freshwater reaches into disconnected river pools Reduced depth and quality of water in the freshwater reaches (especially in the pools). Reduced biodiversity of flora and fauna within the freshwater habitat that remains	Survey pool habitats in freshwater tributaries to show the spatial extent of these regions. Assess the extent and value of weirs on the Avon as freshwater species refuges and prepare management strategies with relevant stakeholders Assess increasing environmental flows	*High
Mudflats	Low - medium	Landward migration of the intertidal zone and shallow subtidal zone in the lower estuary (providing undeveloped land to accommodate sea level rise).	Determine spatial extent and total area of intertidal and shallow subtidal mudlflats at present and with the expected sea level rises to ensure there is no significant diminution in this important habitat Assess reserves to determine the extent to which landward extension is possible Development should accommodate landward extension	Low - medium
Acidification/ buffering capacity	Low (slow)	Calcification process inhibited Potential change in biodiversity	Review the potential effects of acidification on the ecology of the Swan Canning ecosystem, so that the potential risks can be assessed	Low

* not a high return for investment., limited options for mitigation/ adaptation

To adapt to change in community structure and trophic dynamics, ecological resilience models predicting the effects of water quality changes (particularly salinity and dissolved oxygen) from the lower to upper estuary should be developed. They will assist in the prediction of the spatial distribution of community structures.

Adaptation actions to ameliorate the impacts of climate change upon the river system, and subsequently upon birds, include:

- Where possible, allow tidal habitats to shift landward (see mudflat adaptation);
- Create sandbars;
- Reduce disturbance at shoreline roosting sites;
- Supplement freshwater sources in the lower estuary; and
- Revegetate fringing environments with plants able to cope with changed conditions.

To better understand the likely impact of climate change on fish communities, appropriate scenarios need to be explored as part of the Western Australian Marine Science Institute (WAMSI) initiative (under project 4.3). This project is designed to provide an improved understanding of how food webs in the Swan and adjacent estuaries are affected by fishing, through the development of qualitative and quantitative models.

The models will assess how fisheries and their supporting ecosystems may respond to changes in the environment and to different management actions. An initial recommendation for action is to consider how the composition of each of the life-cycle categories, and as a consequence recreational and commercial fishing amenity, might change as a result of climate change. Subsequently, every effort should be made to incorporate this understanding into the development of appropriate climate change scenario evaluation built into the WAMSI Node 4, Project 4.3. This will enable the development of more precise predictions of the likely effects of climate change on fish and fisheries of the Swan.

Seagrass and macro-algae are an important habitat and food source for fish and invertebrates, and play an important role in nutrient dynamics (e.g. enhancing denitrification rates). The distribution of these macrophytes in the lower Swan Canning estuary appears to be fairly stable, but needs to be mapped as this has not been done for several decades. The predicted distribution of seagrass that is possible with the expected sea level rise needs to be examined, to ensure there is no significant diminution in this important habitat. Further, the reserves adjacent to important areas of seagrass – and along the entire lower estuary – need to be assessed for the extent of any landward extension of seagrass that could occur. Planning of development adjacent to the rivers will need to accommodate any landward extension of seagrass that is necessary for the ecological health of the Swan Canning river system. A research priority in this area is the prediction of the potential impacts of climate change on water clarity.

Loss of freshwater biodiversity will result in changes in the ecology of the Swan and Canning rivers. Freshwater tributaries are important summer refugia of freshwater fauna. Changes to salinity in the main channel of the Swan River, may result in the further isolation of these refuge habitats and this should be monitored. An adaptation strategy to maintain these residual environments may be through environmental flows in systems downstream from reservoirs. However, a preliminary requirement is to establish the spatial extent of freshwater tributaries, which can be achieved through surveys. In addition, the extent and value of weirs on the Avon as freshwater species refuges should be assessed and management strategies prepared with relevant stakeholders.

To adapt to the potential loss of mudflats, there is the need to ascertain the current spatial extent and total area of intertidal and shallow sub-tidal mudflats. Further, the spatial extent of existing mudflats should be determined under the expected sea level rises - to ensure there is no significant diminution in this important habitat. The reserves adjacent to important areas of mudflats – and along the entire lower estuary – need to be assessed to determine the extent of any potential landward extension of mudflats. Planning for development adjacent to the rivers will need to accommodate any landward extension of mudflats that is necessary for the ecological health of the Swan Canning river system. As such, establishing this information is a priority for the region. A more radical approach would be to investigate the potential to use treated wastewater to augment environmental flows, such as in the Hawkesbury River, NSW.

To adapt to changes in geomorphology, a spatially-based risk matrix should be developed to identify high-risk areas and likely consequences. In addition, the existing riparian vegetation should be mapped onto the risk matrix and projected changes modelled. This will show where there are risks of bank erosion and sediment remobilisation - and during what time frames. Management strategies can then be developed, such as biological stabilisation or engineering structures such as revetment works.

Finally, to manage the uncertainty and impact of climate change, a clear understanding of key social, cultural and amenity values for the community with respect to the forecast changes in the Swan Canning must be established using appropriate models to express environmental/ecological risks (to partition risk into ‘likelihood’ and ‘consequence’). These models can be used to facilitate the management of the change process, including intergenerational expectations and to help focus where resources should be committed. This adaptation strategy is in line with adaptation priorities to address human health and social impacts.

3.2.2 Adapting to human health and social impacts

The nature and degree of adaptation to meet aesthetic and cultural needs will depend on the reaction of the community to the changes. To some planners and community members there will be a desire for as little change as possible. For others, change will be tolerated in some areas and to some extent but there will be a desire to protect key features. For still others the change will provide an opportunity to alter the landscape to what they perceive as a more aesthetic or accessible landscape through urban developments of different kinds. It will be important that these views are understood and incorporated in iterative planning with a high degree of public involvement to create the best possible landscape in aesthetic terms. Climate change needs to be a central focus of river planning and management so that change can be planned for holistically. A piecemeal approach is almost certain to create a disjointed and less than satisfactory landscape.

Significant investment in the modification of recreation-based infrastructure such as jetties and bridges in order to adapt to the impacts of climate change, whilst ensuring adequate access to the river, may be required. These modifications would be beyond that required from the expected increased demand without climate change. Walking paths may have to be relocated or even abandoned if the setback required for housing is no longer available in some areas. The open areas that provide for family and group activities and for the exercising of pets may have to be significantly curtailed. Potentially, more restrictions on the use of open space may have to be considered. Regulation of the types of boats and their activities in the river may also be required to assist in preventing further bank erosion as that is already a significant concern.

Adaptation strategies to human health risks are under assessment in the Health Impact Assessment Program related to climate change in Western Australia. The program involves the Department of Health, Curtin University and the World Health Organisation. Through the program, waterborne disease has been recognised as a potential area that will require significant adaptation. From the Swan River Trust’s viewpoint active participation in this statewide program to identify areas in which management of the Swan may have to change over time is of high priority.

Finally, there is a need to identify and develop mitigation strategies for any threats to infrastructure that have historical significance or value for the long-term values in relation to stewardship. There will be an important need to work with the Nyungah community to ensure that areas of importance are identified and appropriate strategies put in place to provide sustainable management for significant indigenous sites. This work could parallel the systematic programs to tackle climate change challenges for indigenous communities that are now evolving in Northern and remote Australia.

Table 21 Human health and social impacts of climate change, adaptation strategies and risk rating

Area / risk	Likelihood	Adverse Impact of climate change	Mitigation and adaptation	Risk rating
River landscape and management	Low	Loss of beach environment Physical changes will alter the aesthetics of meaning of the landscape	Incorporate social values into iterative planning	Low
Recreation and tourism	Medium - high	Restrictions to access Change in ephemeral parts of wetlands Altered fishing	Investment in recreation based infrastructure Possible restrictions on availability of open space Regulation of access – boat and pedestrian	Low -medium
Recreational fishing	High	Depends on species specific changes. Some species will be favoured others disadvantaged	Refer to Table 20 above. Limited options for mitigation and adaptation	High*
Human health	Low	Increase numbers of mosquitoes Fish dangerous for consumption Water contact health risks exacerbated	Active participation in statewide programs that address human health impacts of climate change	**
Cultural and Indigenous issues	Low	Alteration of the importance of River to the community Loss of scared sites	Identify and develop mitigation strategies for threatened infrastructure and sites	Low

* not a high return for investment, limited options for mitigation/adaptation

** refer to Department of Health WA (2007)

3.2.3 Adapting to Impacts on Infrastructure

The key climate change impacts on infrastructure are rising water levels and change in the frequency and intensity of storms. There are a number of procedures that can be considered to mitigate these effects, including:

- provide increased protection of foreshore assets by the use of protective walls and revetments (i.e. construction of larger and stronger structures);
- increase the elevation of infrastructure sufficiently to avoid and/or remove the possibility of damage;
-
-
-
-
-

- apply planning legislation to limit further development in threatened areas and progressively move valuable infrastructure to higher elevations; and
- consider the use of submerged structures to reduce the fetch of storm surges and reduce the energy of waves reaching the shoreline.

Research priorities to determine the appropriate adaptation response include:

- obtain a detailed knowledge of contours of low-lying land around the perimeter of the Swan Canning river system. To be of suitable value this would need to provide data discrimination in 10 cm intervals (now available and under development through the Urban Monitor project); and
- obtain information on the frequency and nature of extreme events that would have the greatest impact on infrastructure.

The more specific adaptation responses to rising sea levels, by marine infrastructure type, are provided in Table 22. These adaptation approaches account for the service life of the various structures. When the current structures are replaced, during the coming decades, the design of the replacements should account for the changes anticipated during their service life.

Table 22 - Adaptation strategies for marine infrastructure

Item	Likelihood	Adverse impact of climate change	Suggested Response to Impacts from climate change	Risk
Jetties & boat pens	Low - medium	Flooding / waves Sedimentation / accretion	Include 0.1 to 0.3* m sea level rise into designs of replacement jetties and mooring pens as they are replaced	Low
Seawalls & revetments	Low - medium	Flooding / waves Sedimentation / accretion	Where practical include 0.1 to 0.3* m sea level rise into designs of replacement seawalls as they are replaced Retro-fit low seawalls with wave deflectors if required Drainage systems may preclude raising crest levels of seawalls	Low
Groynes	Low	Flooding / waves Sedimentation / accretion	Raise crest level to accommodate 0.1 to 0.3* m sea level rise via maintenance of groynes as required	Low
Boat ramps	Low	Flooding / waves Sedimentation / accretion	Include 0.1 to 0.3* m sea level rise into design of replacement ramps	Low

* The variation in sea level rise design (i.e. 0.1 to 0.3) relates to infrastructure service life (see Table 18).

3.2.4 Adapting to economic impacts

A review of past and existing adaptive and mitigation strategies, locally and in other regions, is necessary to identify future practical adaptive and mitigation strategies for the Swan and Canning rivers.

In short, funding will have to be set aside for either adaptive or mitigation measures. Those costs will likely be:

- associated with improved stability of river banks;
- associated with ensuring riparian zones are vegetated in order to reduce erosion;
- used to prevent further degradation of estuaries; and
- associated with repairing or altering existing infrastructure.

However, certain expenses may be shared between the government and private institutions. For example, costs associated with infrastructure upgrades can potentially be partly subsidised leaseholders of river estates and the cost of building dams or walls to prevent floods could be shared with local businesses that are going to be directly affected. Some costs can be fully covered by private ownership, such as the cost of raising low-lying private land. Private owners will have a vested interest in paying for these adaptive measures as they may result in lower insurance premiums.

It is important to note that any costs associated with mitigation or adaptive measures should always be weighed against the benefits prior to any decision on implementation. With certain problems, mitigation measures may be more feasible and more cost effective both in the short and long run than adaptive measures. Also, accurate prediction of the types and extent of impact of climate change are crucial in determining the cost and benefits of each mitigation or adaptive measure. Review of current adaptive and mitigation strategies in other regions will prove useful in this regard. However, the south west of Western Australia is experiencing as severe a climate change as anywhere in the world and therefore, answers may not be found in other regions at this stage.

Decision support tools and tools for measuring economic impact are important for assessing the economic impacts of climate change. Adoption of decision support tools such as Cost Benefit Analysis (CBA) and Multi-Criteria Analysis (MCA) can help in efficient allocations of funds to projects that will provide the most desired outcome (Hajkowicz et al. 2006). This is achieved through a better understanding of economic efficiencies of climate adaptation investments.

Costs and benefits of adaptation can be tangible and intangible. Tangible costs and benefits can be observed from the market, such as reduced revenue from tourism due to poor water quality in lakes and rivers. Intangible costs, such as reduced welfare, although not observable in market transactions, can still be measured using non-market valuation techniques, such as willingness-to-pay.

Climate change has social, environmental and economic impacts. The impacts from climate change should therefore be considered in conjunction with other issues affecting the same management strategies. Full economic evaluation of the increased risk of damage to existing infrastructure assets from climate change as a result of rainfall intensity during storms, or as a result of the drying climate, is recommended once the magnitude of these impacts is better known and the efficacy of intervention is established. Cost of externalities from social and environmental impacts should also be incorporated into the marginal cost of the projects to reflect the social marginal benefit.

Increased investment in understanding the social and economic impact of climate change is also necessary. For example, the impact of changing water quality and water level in rivers and lakes, which result in reduced aesthetic values, increased health risks, and reduced tourism should be assessed. Revealed preference economic valuation techniques such as the hedonic property price approach can be applied to estimate the capitalised amenity value on property prices as a result of being closer to lakes and rivers of different qualities. This will enable a better understanding of how water quality can improve social welfare.

Finally, social and economic impact from health risks due to climate change can be evaluated using health economics (i.e. the number of people hospitalised and the cost of working hours lost due to hospitalisation) or non-market valuation techniques (i.e. willingness-to-pay to avoid health risks).

The risk rating for the Swan River Trust, to adapting to economic climate change impacts are presented in Table 23.

Table 23 Economic impacts of climate change, adaptation strategies and risk rating

Area	Likelihood	Impact of climate change	Adaptation	Risk
River health	High	Reduced water quality and increased costs for intervention and monitoring programs	Apply valuation techniques to aid allocation of funds to areas and projects. Incorporate social marginal benefit into the marginal costs of projects	High
Utility infrastructure (power, water, drainage & roads)	High	Increased risk of infrastructure degradation and failure	Apply valuation techniques to aid allocation of funds to areas and projects Incorporate social marginal benefit into the marginal costs of projects Full economic evaluation of increased risk of damage to existing infrastructure recommended	Medium
Insurance	Low	Increased premiums and/or reduced coverage	Full economic evaluation of increased risk of damage to existing infrastructure recommended	Low

3.3 Summary

The key management strategies and research priorities for the adaptation to climate change impacts in the Swan Canning river system have been outlined in this chapter. The strategies are baseline adaptation responses that can be, and should be, implemented now, to reduce the impact of climate change on the Swan Canning river system. As the Swan River Trust addresses the adaptation priorities outlined in this chapter, and as climate change science is updated, the Trust will reassess its management position, and consequently update its research and adaptation priorities. This adaptive management approach will ensure that the Trust is in the best position to adjust to the impacts of climate change.

4 Planning for adaptation

The Swan River Trust was established in 1989 with planning, protection and management functions for the Swan and Canning rivers and associated land. During the last few years these functions have been streamlined to address the need to improve land use planning, water quality and the health of the Swan Canning river system.

The Trust plays an important role in protecting and enhancing the ecology, health, visual and social amenity of the Swan and Canning rivers through statutory planning programs. Programs ensure land use planning and development in the Trust's Development Control Area continue to protect community and ecological values of the system. This chapter provides a summary of the potential impacts of climate change on planning in the Swan Canning river system.

4.1 Planning legislation

The *Swan and Canning Rivers Management Act 2006* ('SCRM Act') was proclaimed in September 2007 and brings changes to the statutory and regulatory processes (Swan and Canning Rivers Management Regulations 2007 - SCRM Regulations 2007) and functions previously performed by the Trust under the *Swan River Trust Act 1988*. The Trust has overall planning, protection and management responsibility for the Swan Canning river system under Part 5 of the SCRM Act. The Trust provides advice, makes recommendations to and comes under the jurisdiction of the Minister for the Environment.

The extent of the Trust's planning and development control is defined by a Development Control Area (DCA). It comprises generally the waters of the Swan Canning river system, including areas reserved under the Metropolitan Region Scheme (MRS) for 'waterways' and lands adjoining those waters that are reserved Parks and Recreation. The Riverpark area, managed by the Trust, comprises all of the above excluding freehold land in private ownership. The DCA can be amended from time to time by Regulation, to reflect changes to river conditions or management needs.

The Trust provides advice, considers and makes recommendations on development and land use applications that affect the DCA under five different statutory processes and under two State Government Acts.

The Trust's statutory planning functions:

1. Make recommendations to the Minister for the Environment concerning development proposals in the DCA.

2. Provide advice to the Western Australian Planning Commission (WAPC) concerning amendments to the MRS and other strategic planning instruments.

3. Provide advice to the WAPC in relation to subdivision proposals.

4. Provide advice to the WAPC in relation to development proposals in accordance with Clause 30A of the MRS.

5. Provide advice to local governments on development applications, local planning scheme proposals or other local planning proposals that may affect the DCA such as structure plans and outline development plans.

6. Provide advice to and obtain advice from public authorities concerning their responsibilities in terms of the SCRM Act 2006.

7. Provide clearance of development and subdivision conditions of approval and provide advice on the implementation of the approvals.

8. Update the procedural matters associated with development assessment, review the Trust's development control policies, model conditions and review the Trust DCA boundary as necessary.

State and local government planning and regulatory instruments control adjoining land use and development that can directly or indirectly impact the river system. The MRS and any other region planning scheme applicable to the metropolitan region cannot be made in a manner that is inconsistent with the provisions of the SCRM Act. Also, if a strategic document in force under the SCRM Act 2006 Part 4 relates to land or waters that are within or abut the district of a local government referred to in Schedule 7 of that Act, the local government in preparing or amending a local planning scheme is to have due regard to that management program.

Land use planning legislation provides measures by which planning for climate change can be addressed. The legislation can be implemented through the head powers contained in the *Planning and Development Act 2005* (P&D Act) or through application of local planning schemes and other statutory instruments prepared under the P&D Act.

The principal measures by which planning for climate change can be addressed include:

- control of land use and development (through zoning, reservation and special control areas);
- control of subdivision (including reservation, works and infrastructure);
- funding of infrastructure (in conjunction with subdivision and/or development); and
- acquisition of property and redevelopment or reservation.

In addition to the powers available under the land use planning legislation, local and State governments also have a wide range of powers available under various other legislative tools. In some cases, these provide alternatives to planning powers while in others they are complementary. Building controls and powers to undertake public works are of particular relevance in responding to climate change. These will be addressed in this chapter, in addition to measures commonly applied under the auspices of land use planning.

4.2 Adaptation responses to climate change impacts on existing development

Climate change impacts relevant to land use planning, and those potentially amenable to planning or associated responses, include:

- sea level rise;
- foreshore erosion;
- storm surge inundation;
- stormwater run-off reduction;
- salt water intrusion;
- reduced rainfall; and
- increased temperature.

Table 24 Adaptation measures

Planning instrument	Adaptation measure
Land use planning	Adjust foreshore reserves to provide an extended buffer to accommodate encroachment due to higher water levels.
	Impose special control areas over private land affected by occasional inundation. These might limit land uses, types of development, including buildings, structures and materials.
	Require ‘memorials’ on title or other similar caveats to ensure prospective purchasers and/or lessees of affected property will be aware of the potential for inundation.
Public works	Relocate and/or re-construct foreshore development such as restaurants/cafes, yacht/rowing clubs and amenity buildings.
	Re-construct facilities such as boat launching ramps, parking areas, jetties and ports.
	Re-engineer drainage utilities, including the re-positioning and/or re-sizing of drainage outlets so as to facilitate discharge and/or maintain wetland ecology.
	Re-engineer and/or realignment of infrastructure such as roads, paths and bridges which will be affected by frequent high water levels.
	Provide foreshore protection works such as walls, breakwaters and stabilisation of the near-shore river-beds.
	Provide foreshore stabilisation and/or rehabilitation such as sand/soil replenishment and associated plantings, to protect facilities and maintain environmental values.
Re-development	Re-develop and/or modification of existing buildings to provide protection from frequent inundation.
	Remove buildings that will be seriously affected by frequent inundation and where protective measures would compromise the river environment.

Amelioration / adaptation	Provide detention and/or retention of stormwater run-off to limit flow-rate into the existing drainage system and increase recharge of aquifers.
	Limit clearing and/or replanting of catchment areas to maintain water-table clearances, facilitate the re-charge of stormwater and reduce stormwater run-off.
	Limit groundwater abstraction in riverside areas so as to reduce salt-water intrusion caused by reduced aquifer re-charge.
	Require rainwater tanks and grey water recycling facilities so as to reduce the pressure on public water supplies and groundwater aquifers.
	Increase the requirements for energy efficiency, in particular the energy required for space cooling, due to increasing temperatures.

Implementing the adaptation options presented in Table 24 would involve significant expenditure of funds by public authorities. Therefore, a financial plan including long-term funding will be an essential part of any response strategy. As indicated previously (section 3.2.4 - Adapting to Economic Impacts) it is likely these costs will need to be shared between public authorities and private landowners. Many of these measures will be achieved through normal life-cycle costs or replacement. Additionally, private investment in recycling of property and infrastructure will be determined through time and be controlled by application of emerging planning policy or statutory planning processes.

By adopting a staged response, based on the timing of climate change and its effects, the financial burden could be managed more sustainably. Clear definition of public and private good components of adaptation investment will facilitate staged adaptation by minimising equity arguments between institutions and landholders. Staging of development and re-development would also provide time for adjustment to changes, including adjustment of expectations by those directly affected.

4.3 Response to planning of new areas

Any planning instruments to control land use and development on land likely to be affected by climate change, including inundation or storm surges, requires an accurate and detailed understanding of those impacts as well as the application of appropriate, sound, technical or scientific advice on which to base the control measures. To avoid, or at least minimise the need for expensive amelioration as discussed above, planning and development decisions in relation to new areas need to give greater recognition to the potential impacts of climate change.

While some of the responses to climate change for new development will be similar to those for existing development, there will be opportunities for a more precautionary approach than has sometimes been the case in past planning. In addition to the proposed approaches for existing development, issues to be addressed in conjunction with the planning and development of new areas include:

- land suitability assessment (exclusion of land that is susceptible to frequent inundation, including storm-surge, from permanent physical development);
- regional development and growth-management strategies to identify and limit the use of land likely to be ‘at risk’, and
- negotiate cost sharing between public and private investment (through development contributions at the time of subdivision or development of the land).

5 Key findings

This report has identified the main potential threats and impacts of climate change to the health and amenity of the Swan Canning river system based on available knowledge. It also provides strategies for the community to help reduce vulnerability and increase resilience to the impacts.

5.1 Projected changes

The most recent scientific information derived from current climate observations, predictive modelling and expert opinion suggests that in the future the Swan Canning river system will experience:

1. continued increases in atmospheric and water temperatures;
2. an acceleration in sea and river-system water level rise;
3. decreases in winter rainfall and streamflow;
4. decreases in groundwater levels and consequent flows to drains and streams; and
5. increases in warm spells and heat wave frequency.

5.2 Impacts of climate change

This report explores the major implications of the projected changes on important components of the catchment, ecology, social values, infrastructure and economics in the next 20 – 70 years. Major impacts include.

Avon Catchment

Water, sediment, nutrients and salt loads from the Avon Catchment to the estuary are expected to reduce with widespread drying. The hotter and more arid climate will alter the distribution of native vegetation and land use practices in the region. Fuel loads will take longer to accumulate but fire seasons will be longer.

Ecology

The key impacts on the ecology of the Swan Canning river system will be driven by sea level rise and reduced streamflow, which will increase the period of salinity stratification and the penetration of marine water upstream. Key biological processes will be affected, including biological oxygen demand, nutrient cycling and sediment retention. Changes in the distribution and abundance of species are very likely and seasonal patterns of productivity and food-web dynamics will almost certainly be altered. The lower estuary, which experiences marine conditions for much of the year will be least affected. The upper estuary will be most affected with increased and ongoing problems associated with eutrophication, such as algal blooms and fish kills.

Social values

The social values of the system are likely to be threatened by a reduction in passive recreational facilities through loss of beaches, wetlands and associated vegetation throughout the lower, middle and upper estuary. Loss of aesthetic value may occur due to a greater frequency of algal blooms and fish kills in the upper estuary, which lead to public perception of an unhealthy environment. Increased development of infrastructure to mitigate sea level rise, including seawalls, revetments and barrages will alter the current iconic Western Australian landscape to produce a more ‘European’ or ‘artificial’ landscape.

Because of the uncertainty involved it will be important to maintain good communications with river users and residents so that everyone agrees and understands the means of adaptation and ways to increase system resilience.

Economics

The main economic impacts relate to the increasing costs of water quality management. Reduced water quality has already necessitated considerable investment in a range of remedial projects in the system. Climate change is likely to exacerbate eutrophication and fish deaths in the upper estuary, and increased river and land values may require corresponding increased costs associated with monitoring and intervention programs such as oxygenation.

The increased fish deaths and algal blooms may reduce the recreational amenity and value for recreational users, which may in turn impact local businesses in the region.

Economic loss will also result from a need to protect, retrofit, repair or replace infrastructure due to increased sea levels and storm surges. Mitigation or modification measures may also be required to protect riverside suburbs into the future.

5.3 Adaptation

Climate change will have a profound influence on the Swan Canning river system. ‘Adaptation’ in this report means reducing or accommodating to the adverse impacts of climate change. As critical thresholds are likely to be exceeded, knowledge and ways to increase system resilience will also be essential. The ability to adapt to climate change will be aided by the use of appropriate and robust information on key indicators, which may then be used to develop strategies for protection, accommodation, avoidance or retreat.

The collection and analysis of high quality long-term data on key climate change variables has been clearly identified in this report as a priority goal for management of the Swan Canning river system. Furthermore, any new data should be incorporated into predictive models so that the uncertainty of climate change risks can be assessed and improved into the future. Action towards improving the understanding of the system’s response to climate change will act as a basis for timely implementation of cost effective management measures in the future.

To successfully adapt to climate change, funding needs to be allocated for practical adaptation and mitigation strategies in the following key areas.

- Improving the stability of river structures such as banks, seawalls and riparian vegetation.
- Repair or alteration of existing infrastructure. Significant investment in the modification of recreational based infrastructure will be necessary, beyond that required from expected increased demand without climate change.
- Prevention of further degradation of water quality.

In addition, expanded monitoring and modelling programs are recommended to develop a more thorough understanding of system response and resilience for the ecological components of the catchment and estuary. In particular, emphasis should be focused on understanding the risks associated with changes in nutrient, sediment and salt loads, stratification and light penetration, and the ramifications of these on the biological constituents of the system.

Key biological processes of biological oxygen demand, nutrient cycling and sediment retention should be monitored and continually assessed so that intervention measures can be implemented where necessary to address changes in ecosystem function.

Information and consultation exercises that can demonstrate the effects of climate change on iconic species will help enlist public support. The biology and ecology of iconic Swan Canning species should be further investigated (and models developed) to understand and predict their response to environmental change and management action.

There is a need to identify and develop mitigation strategies for any threats to infrastructure with cultural, historical or economic significance. Investigations are also needed to further understand the social and economic impacts of climate change.

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Disclaimer

The information summarised here is based on results from computer models that involve simplifications of real physical processes that are not fully understood. Accordingly, no responsibility will be accepted by the Technical Advisory Panel or the Swan River Trust for the accuracy of the assessments inferred from this work or for any person’s interpretations, deductions, conclusions or actions in reliance on this information

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Appendix 1:

Draft Scenarios for Swan River Trust Climate Working Group

Global Scenarios

Themes underlying the proposed scenarios

Two key scenarios for south west Western Australia are used in this draft. These scenarios are derived from two key scenarios (A2 and B1) of the recent IPCC Fourth Assessment Summary and are described in more detail the appendix of the IPCC (2007a) report.

The A2 scenario represents a future in which global response to mitigation of climate is only marginally successful. It might be typified as a ***politically weak*** scenario, but not a worst case of business as usual.

The B1 scenario represents a future in which the world community achieves outcomes consistent with early and aggressive commitment to stabilisation and reduction of greenhouse gas emissions. It might be typified as ***a politically strong response*** since, in terms of common human behaviour and global cooperation it represents a challenge that is near the limits of political credibility. The scenario might be labelled aspirational but it is a scenario that falls short of achieving the safe CO_2 $_e$quivalent goal of 450 ppm.

A third scenario A1B was considered. It is intermediate between the A2 and B1 scenarios and one that implies belated success in emissions control and a better end of century outcome than A2. It might be typified as a ***compromise*** scenario. However, in mid-century time frames there is insufficient differentiation to warrant a third scenario for most purposes of this report.

The equivalent CO_2 equivalent concentrations at 2100 associated with these scenarios is shown in Table A1.

Table A1 Year 2100 carbon dioxide equivalents of key scenarios

SRES scenario	Approx. CO_2 equivalent at 2100
A2	1250
A1B	850
B1	600 (~550)

*Approximate CO2 equivalent concentrations ppm corresponding to the computed radiative forcing due to anthropogenic greenhouse gases and aerosols in 2100

B1 is a stabilisation scenario with CO2Equiv levelling out at 550 to 600 ppm. A2 is not a stabilisation scenario and reaches 1250 ppm at 2100. A1B achieves belated stabilisation at around 850 ppm.

South west Western Australian scenarios

Themes of the proposed scenarios

Two main scenarios are proposed for the Swan Canning Catchment of south west Western Australia. They are labelled **A2# and B1#.**

The scenarios are interpretations of A2 and B1 type global scenarios based on local interpretive material from sources such as IOCI and CSIRO/BMRC studies, including studies commissioned by State bodies such as the Department of Water.

The scenarios have also been supplemented by data recently available from the Technical Report – Climate in Australia (CSIRO 2007), which was released in October 2007 in conjunction with Greenhouse 2007.

The scenarios are driven by and broadly consistent with global warming projected in Table A2 following.

Table A2 Projected mean surface global warming for the selected scenarios

Data source: IPCC fourth assessment summary for policy makers (Fig. SPM-5), February 2007

SRES Scenario	Warming °C relative to 1990		
	2030	2070	2100
B1	0.8	1.6	1.9
A1B	1	2.2	2.8
A2	0.8	2.3	3.6
SD range*	0.6 to 1.2	1.3 to 2.6	1.4 to 4.1
Mid range	0.9	2	2.8

* Envelope of standard deviations of the three scenarios roughly 90% probability of outcome in this range

To reconcile with observed local change, which may be affected by other anthropogenic factors (e.g. land clearing) as well as multi-decadal variability, some adjustments have been assumed, most particularly in respect to rainfall and streamflow where priority has been given to available local studies that have down-scaled from global forcing.

Large gaps remain in local interpretive material that has currency with the science underpinning the Fourth IPCC Assessment. However, the recent Climate in Australia report has enabled some late improvements. Where necessary gaps have been filled by judgements: interpolating; extrapolating; or factoring in available data. However, with the availability of the October 2007 material, such infill has been minimal.

The scenarios are drafts and must be viewed as such. They are not predictions, but reflect plausible alternative circumstances that might be encountered in future river management. The selected 'marker' scenarios seek to encompass higher and lower levels of success in mitigation whilst remaining in a realm judged as realistic (not extreme) and the range embraces:

- fragmented and only weakly effectual global responses (A2); and
- strongly effectual global responses aiming at 'safe' levels of stabilisation (B1).

For adaptive policy there is a need for scenario selection to be mildly pragmatic about human political achievement. At the side of mitigative failure, the A2 and A1B scenarios do better than a business as usual scenario but reflect 'soft' political responses. At the success side, the B1 scenario achieves a 550 ppm CO_2 equivalent stabilisation, which would demand a strong political response but, even so, would fall short of the preferred aspirational goal of 450 ppm CO_2 equivalent.

As with the IPCC Fourth Assessment the scenarios generally exclude the consideration of possibly dangerous instabilities in global climate and in this sense are inclined towards conservative optimism with regard to extremes. This is a limitation in risk management for long-term time scales and where matters such as long-term sea level are relevant to decision-making, some risk averse emphasis may be required. However, the scenarios do imply conditions that will force inevitable change in regional environment. The scenarios can be refined and expanded by further work and dialogue. This is desirable.

Table A3(a) Projected annual mean warming* - south west (surface level) relative to 1990

Multi model means and 90 percentile ranges NOTE: The italicised figures are the 90 percentile range of a multi-model ensemble			
Scenario	**Warming ˚C relative to 1990**		
	2030	**2070**	**2100**
B1#*	**0.8 ***	**1.4 ##** *(1-2) ##*	**1.6 ***
A1B#*	**0.8 ##** *(0.6-1.2) ##*	**2***	**2.4 ***
A2#*	**0.8 ***	**2 ***	**3.0 ***
A1F1	**0.8 ***	**2.7 ##** *(1.9-3.8) ##*	**3.4 ***

*Approximations on assumption that S/W changes are 0.85 of projected global mean given in the SPM

Perth figures from CSIRO, 2007, p 135

Table A3 (b) Projected mean surface warming and evaporation - south west

Element	Scenario	Change relative to	1990	2030	2070	2100
Mean land temperature increase °C - south-west	B1#	1890	0.6 °C	1.4 °C	2.0 °C	2.2 °C
	A2#			1.4 °C	2.6 °C	3.6 °C
Hot days >35°C Perth Airport based on CSIRO, 2007, p 135	B1#	NA	27	>35	~41	?
	A2#			~35	~54	?
Mean sea temp increase - south-west- based on CSIRO, 2007, p 100	B1#	1890	~0.6 °C	1.0-1.2°C	1.8-2.0 °C	-
	A2#			1.0-1.2 °C	2.1-2.6 °C	-
Potential evaporation increase based on CSIRO, 2007, pp 80-81	B1#	1990	NA	-	+2%	-
	A2#			-	+7%	-

Table A4 Projected mean winter rainfall decrease - south west

Element	**Scenario**	**Observed 1990 as % decrease from 1925-75**	**Rainfall decrease as % change from 1925-75**		
			2030	**2070**	**2100**
Total winter rain decrease from 1925-75	**B1#**	**10%***	**7~14%**	**16~25%**	**17~27%**
	A2#	*Possibly not all GHG driven	**12~20%**	**22~34%**	**26~40%**
	Scenario range		**7~20%**	**16~34%**	**17~40%**

Assumptions

Greenhouse Gas driven (GHG) rainfall decrease coefficients (50 percentile range of ensemble runs) beyond 1990, are derived from multi-model studies by Charles. **Their 1990 baseline needed adjustment to accommodate GHG and other attributed causes in the observed post 70s decrease. This adjustment (Appendix 2) involved the following assumptions -**

1. **At 1990** the gross observed shift in winter rainfall reduced it to 90% of 1925-75 mean (IOCI Climate Note No. 5/2004)
2. **GHG was assumed to have reduced it to 95%, other anthropogenic (OA) effects to 98% of 95% and multi decadal variability (MDV) combined with OA to 94.5% of 95%** (equivalent to MDV causing 30% of observed reduction)
3. As the GHG affected rainfall further decreases the OA and MDV contributions were assumed to remain as a fixed proportion of the base rainfall. In some scenarios the MDV effect might disappear with time and **this possibility was allowed to widen the projected uncertainty range.**

Table A5 Projected streamflow decrease - south west

Element	Scenario	1990 as % decrease from 1925-75	Flow decrease as % change from 1925-75		
			2030	2070	2100
Streamflow decrease from 1925-75	B1# – A2# scenario range	30%	22~55%	45~75%	50~80%

Assumptions
See rainfall assumptions above
Streamflow at 1990 was 70% of 1925-75. Further decrease estimated as follows-
10% rain decrease ~ reduces to 67% of original (1925-75) flow,
20% rain decrease ~ reduces to 67% of 67% = 45% of original (1925-75) flow,
30% rain decrease ~ reduces to 30% of original (1925-75) flow,
40% rain decrease ~ reduces to 20% of original (1925-75) flow

Table A6 Projected sea level rise - south west

Element	Scenario	Change relative to	2000	2030	2070	2100
Sea level rise excluding future rapid dynamic change in ice flow	B1#	1897	~0.16m	0.22m-0.33m	0.28m-0.43m	0.35m-0.55m
	A2#				0.3m-0.5m	0.4m-0.7m
Sea level rise - including future rapid dynamic change in ice flow	B1#					0.5m-0.7m
	A2#					0.6m-0.9m

Table A7 Projected changes in extreme rainfall - south west

Element	Scenario	Change relative to	1990	2030	2070	2100
Winter daily rainfall intensity 99th percentile	B1#, A2#	1925-75	lower (see CSIRO, 2007 p74)			
Winter rain day frequency **	A2#	1990	100%	94-97%	80-90%	70-85%
	B1#		100%	97-100%	95-97%	80-90%
Summer daily rainfall intensity 99th percentile	B1#, A2#	1925-75	similar**	no robust data - no significant change more likely than not (see CSIRO, 2007 p74)		
Summer rain day frequency	B1#, A2#	1925-75	similar	no robust data - no significant change more likely than not		
** See IOCI Stage 2 Draft Full Report (CMIS Paper)						

Table A8 Projected changes in extreme flood flows - south west

Element	Scenario	Change relative to	1990	2030	2070	2100
Winter 10 to 25 yr annual extremes	B1#, A2#	1925-75	lower			
Winter flood event frequency	B1#, A2#	1990	lower			
Summer 10 to 25 yr annual extremes	B1#, A2#	1925-75	similar	no robust data - no significant change more likely than not		
Summer flood event frequency	B1#, A2#	1925-75	similar	no robust data - no significant change more likely than not		

Table A9 Qualitative summary of trends

Observed and projected (south western Australia/Swan Canning river system) climatic or climatically associated trends from global human development

Phenomenon and direction of trend	Likelihood that the trend established or consolidated in late 20th century	Likelihood that anthropogenic climate change has contributed t to the observed trend	Likelihood of future trend under A2#/ B1# scenarios
Accelerating atmospheric and ocean warming (now rising at 0.2O C per decade)	Virtually certain	Virtually certain	Virtually certain
Autumn seasonal rainfall decrease (significant	Very likely	Very likely	Likely
Winter seasonal rainfall decrease (significant)	Very likely	Very likely	Extremely likely
Spring seasonal rainfall increase (small)	Low significance	No robust evidence	Likely decrease
Summer seasonal rainfall increase (small)	Low significance	No robust evidence	Small decrease more likely than not
Decrease in total winter stream-flows (large)	Virtually certain	Very likely	Extremely likely
Increased frequency of droughts	Very likely	Very likely	Extremely likely
Decrease in frequency/intensity of extreme winter rainfalls (1 to 10 year return period)	Likely	More likely than not	More likely than not
Increase in frequency/intensity of extreme summer rainfalls (1 to 10 year return period)	Small or non-existent Statistically inconclusive	No evidence	No evidence for significant change
Decrease in frequency/intensity of winter flood flows (Swan tributaries)	Extremely likely	Extremely likely	Likely
Increase in frequency/intensity of summer flood flows (Swan tributaries)	No clear evidence	No clear evidence	No evidence for significant change
Accelerating sea and tidal estuary level rise	Virtually certain	Virtually certain	Virtually certain
Increase/decreased risk of storm surges which superimpose on sea level rise and flood flows	Uncertain- No conclusive evidence	Uncertain- No conclusive evidence	Uncertain- No conclusive evidence
Increase in extreme tidal estuary levels	Virtually certain	Virtually certain	Virtually certain
Increased frequency of warm spells and heat waves	Likely	Likely	Extremely likely
Increased potential evapo-transpiration	More likely than not	More likely than not	Likely

Vegetative change (xeric shift) in uplands catchments	Very likely	Very likely	Extremely likely
Vegetative change (xeric shift) in coastal catchments	Unlikely **	Unlikely	Very likely
Increased fire hazard##	More likely than not	More likely than not	Extremely likely

** Observed change on coastal plain appears to have been dominated by non-climatic influences (so far)

Relates to underlying risk before management intervention

In this report the following IPCC (2007) terms are used to indicate the assessed likelihood, using expert judgement, of an outcome:

Likelihood as % probability of occurrence

Virtually certain	Extremely likely	Very likely	Likely	More likely than not
> 99%	> 95%	> 90%	> 66%	> 50%
	Extremely unlikely	Very unlikely	Unlikely	
	< 5%	< 10%	< 33%	

Appendix 2:

Rainfall/streamflow scenario calculations

The issue

The time series of annual (winter) south west rainfall totals shows a marked step reduction in the mid 1970s. The observed relative change was bigger and more sudden than expected from climate modelling of global warming (see Section 2.6.6). The favoured opinion from IOCI research is that the step 'change' was due to some combination of:

- trends driven by global warming from GHG emissions **(GHG)**;
- a possible temporary perturbation of multi-decadal variability and chaos **(MDV)**; and
- other secondary anthropogenic causes, including land clearing **(OA)**.

Most of the recent statistically downscaled modelling of greatest value in future projection of south west rainfall uses analyses that project percentage change (decrease) from 1990 as a base year. Given that there was a previous marked percentage decrease around 1970, judged as most likely to have been only partly driven by (GHG) warming, the question arises as to what is the appropriate rainfall to assign to 1990 when used as a base for 21st century projections of cumulative decrease.

Projecting from a 1990 base - high, optimistic and middle baseline options

The 1970s climate shift was sufficiently profound and sustained that, whatever its cause, and however much of the shift was permanent, it **has created a new climatic experience that must be taken into account in defining future expectations.**

Future modelled scenarios which project from a 1990 base, need to reconcile in some meaningful way with the observations of the 1970s and the fact that the 1970s shift was an 'apparent' change that exceeded modelling expectations.

The <u>most extreme high-end assumption</u> for projecting on from the 1990 base **would be to assume that all the 1990 recorded observed decrease represents a "permanent" shift** entirely due to GHG warming trends and that (relative) post 1990 GHG projections proceed from that new base. This extreme high-end assumption, that all the apparent rainfall decrease at 1990 was due to GHG warming (and modelling has been significantly underestimating) **has not been used in constructing A2# and B1# scenarios for this report.**

The most optimistic assumption would be that only part of the 1990 shift was 'permanent' and the rest was a temporary perturbation due to chaos and other unknown effects **<u>all of which will (GHG excepted) 'recover'</u>** nearer to the norm in due course.

A middle-of-the-road assumption would be that **a "permanent" anthropogenic base shift occurred which was a combination of GHG and other causes (OA)** and that this was coupled with **a multi-decadal perturbation which might or might not 'recover'** in relevant time scales.

The scenario ranges (built onto post 1990 A2, B1 rainfall change ensembles from downscaling of Charles) of rainfall and stream-flow **in this report, and labelled A2# and B1#, are based on the middle-of-road concept.** It is assumed that:

the base shift at 1990 was GHG driven;

some other anthropogenic effects factored <u>more-or-less permanently</u> on this shift *(collectively explaining, with GHG warming about 70* per cent *of observed decrease)* and;

these were all overlaid by factor of multi-decadal variability which might *(optimistic end of range)* or might not *(pessimistic end of range)* ‘go away’ in the period of interest being projected; and

the A2# and B1# rainfall and stream-flow ranges were formed into an optimistic and pessimistic range by the optimistic assumption that the multi-decadal-variability factor goes away or the pessimistic assumption that it persists.

Post 1990 GHG Ensembles for A2 and B1 Scenarios

The most satisfactory available modelling of regional rainfall applies statistical downscaling methodologies, developed for IOCI to achieve regional resolution from global modelling. In practical terms, interpretations of rainfall change from model evaluations of GHG effects are essentially relative rather than absolute. Rainfall scenarios Tables 2-1 and 2-2 below, are drawn from multi-model (CSIRO Mk3 and CCAM models only) trends for A2 and B1 scenarios inferred from ensembles (mostly from a 1990 climate base) analysed by Charles *et al* (2004) and reported in unpublished unabridged reports of IOCI Stage 2 (Bates pers. comm). Streamflow scenario development reflects associated studies applied to the Stirling Catchment (Department of Environment 2004).

Some interpolations on a rainfall decrease per degree Celsius global warming were used, where necessary, to adjust these data to 2070 and 2100 horizons used in this report.

Tables 2-3 and 2-4 then apply the base-line adjustments discussed above to broadly represent:

the median ensemble estimate;

the 50 percentile range of (chaos affected) ensemble runs for the A2 and B1 scenarios; and

with the underlying stated assumptions of baseline adjustment (on the role of other anthropogenic factors and chaos in the actual climate outcomes realised at 1990).

Assumptions for Baseline adjustment

Greenhouse Gas driven (GHG) rainfall decrease coefficients (50 percentile range of ensemble runs) beyond 1990, are derived from multi-model studies by Charles et al. (2004). Their 1990 baseline required adjustment to accommodate GHG and other attributed causes in the observed post 1970s decrease. This adjustment involved the following assumptions.

<u>At 1990</u> the gross observed shift in winter rainfall reduced it to 90 per cent of 1925-75 mean (IOCI Climate Note No. 5/2004)

GHG was assumed to have reduced it to 95 %, other anthropogenic (OA) effects to 98 per cent of 95 per cent and multi decadal variability (MDV) combined with OA to 94.5 per cent of 95 per cent (equivalent to MDV causing 30 per cent of observed reduction)

As the GHG-affected rainfall further decreases, the OA and MDV contributions were assumed to remain as a fixed proportion of the base rainfall. In some scenarios the MDV effect might disappear with time and **this possibility was allowed to widen the projected uncertainty range.**

Streamflow

Streamflow projections in this Appendix (Tables 2-3 and 2-4) aim to reflect streamflows of the Intermediate and West Agricultural Zone (using analyses for Stirling). They are built as a simple geometric progression (graphed below) assuming that each 10 per cent reduction of rainfall produces a 1/3 decrease of flow. As observed elsewhere in this report, stream-flow decreases in the high rainfall zone of the scarp-lands are more marked than in the intermediate/agricultural hinterland.

TABLE 2-1
Percentage increase or decrease from nominated base - observed record and A2 projections

Parameter	**1950** (1925-1975)	**1975** (1960-89)	**1990** (1975-2004)	**2000** (1985-2014)	**2010** (1995-2024)	**2030** (2015-2044)	**2050** (2035-2064)	**2070** (2055-2084)	**2085** (2070-2099)	**2095** (2090-2099)	**2100** (2095-2104)
Temperature increase deg C relative to 1990	**-0.33**	**-0.2**	**0**	**0.18**	**0.36**	**0.8**	**1.6**	**2.3**	3	3.4	3.6
Temperature increase deg C relative to 1900	0.27	0.4	0.6	0.78	0.96	1.4	2.2	2.9	3.6	4	4.2
	Percentage relative to nominated base - observed record and A2 projections										
Rain relative to 1990 Charles'						**89-95 (92)**	**77-89 (83)**				
% points decrease per degree of temp rise						8%/0.8 = 10	17%/1.6 = 10.6				
Rain relative to 1990 Interpolated (on %/deg basis) RED FIGURES ARE INTERPOLATIONS						**89-95 (92)**	**77-89 (83)**	decrease of 17.6(d/ward) 24.4 (upward) (21av) gives **74- 84 (79)**	adjustment to change of 7.65*3.0 = 22.9 converts from 1975 to 1990 base **72-82 (77.1)**	decrease 7.65*3.4 = 26 gives **68-80 (74)**	**66.5-78.5 (72.5)**
Rain relative to 1975 - Charles									**70-81 (75.5)**		
% points per decrease degree of temp rise									24.5%/3.2= 7.65		

Parameter	TABLE 2- 2 Percentage increase or decrease from nominated base - observed record and B1 projections										
	1950 1925-1975)	**1975** 1960-89)	**1990** 1975-2004)	**2000** 1985-2014)	**2010** 1995-2024)	**2030** (2015-2044)	**2050** (2035-2064)	**2070** (2055-2084)	**2085** (2070-2099)	**2095** (2090-2099)	**2100** (2095-2104)
Temperature increase deg C relative to 1990	-0.33	-0.2	0	**0.18**	**0.36**	**0.8**	**1.2**	**1.6**	1.7	1.8	1.8
Temperature increase deg C relative to 1900	0.27	0.4	0.6	0.78	0.96	1.4	1.8	2.2	2.3	2.4	2.4
	Percentage relative to nominated base - observed record and B1 projections										
Rain decrease relative to 1990 Charles’						**96-100 (98)**	**97-99 (98)**				
% points per degree of temp rise						2/0.8 = 2.5	2/1.2 = 1.67				
Rain relative to 1990 Interpolated (on %/deg basis) RED FIGURES ARE INTERPOLATIONS						**96-100 (98)**	**95-99 (97)**	decrease 13.5 d/nward interpolation **83 - 90 (86.5)**	decrease 8.4*1.7 = 14.3 **82- 90 (85.7)**	8.4*1.8 =15.2 **81-89 (85)**	
Rain decrease relative to 1975									**80-88 (84)**		
% points per degree of temp rise									16/1.9 = 8.4		

Table 2-3 Projected winter rainfall and streamflow changes— <u>ensemble median</u> S/W

Projected Change in Intermediate and West Agricultural Zone** Rainfall and Streamflow Development for the Nominal A2#, B1# Scenarios (Ensemble Medians)(1)							
Element	Scenario	Change Relative to	1990 as fraction of 1925-75	Scenario	Rainfall decrease coefficients(1) - adjustments to 1925-75 base		
					2030	2070	2100
Model estimates GHG effect only on winter rainfall Relative to past	A2	1925-75	GHG only coeff. (3) ~0.95 See below GHG + OA + MDV =(~0.90)	A2	.92x.95 = .87	.83x.95 = .79	.725x.95 = .69
	B1			B1	.98x.95 = .93	.87x.95 = .83	.85x.95 = .80
Total winter rainfall relative to past Assumed non GHG components of observed decrease (40%MDV) Combined with modelled GHG	A2 + other anthropogenic only	1925-75	Other anthropogenic +GHG Coeff.(3) = (~0.98)*GHG	A2 +OA	.98x.87 = .85	.98x.79 = .77	.98x.69 = .68
	A2 +OA + multi decadal variability		Other anthropogenic + MDV coeff. (3) = (~0.945)*GHG	A2 +OA +MDV	.945x.87 = .82	.945x.79 = .75	.945x.69 = .65
	B1 + other anthropogenic only		Other anthropogenic +GHG coeff.(3) = (~0.98)*GHG	B1 +OA	.98x.93 = .91	.98x.83 = .81	.98x.80 = .78
	B1 +OA + multi decadal variability		Other anthropogenic + MDV coeff. (3) = (~0.945)*GHG	B1 +OA +MDV	.945x.93 = .88	.945x.83 = .78	.945x.80 = .76
Total % winter rainfall relative to past	A2 range	1925-75	~ 90% (Observed)	A2#	82 - 85%	75 – 77%	65 – 68%
	B1 range			B1#	88 – 91%	78 – 81%	76 – 78%
	Range			Scenario Range	82 - 91%	75 – 81%	65 – 78%
Total winter rain decrease from 1925-75	A2#	1925-75	~ 10% (Observed)	% decrease	15-18%	23-25%	32-35%
	B1#			% decrease	9-12%	19-22%	22-24%
	Scenario range			% decrease	9-18%	19-25%	22-35%
Streamflow decrease from 1925-75	B1# – A2# scenario range rounded	1925-75	~ 30% (Observed)	% decrease from 1925-75	30 - 50%	50 - 65%	55 – 75%

Assumptions

GHG rainfall decrease coefficients (ensemble medians) are derived from multi-model studies by Charles (associated Tables). Their 1990 baseline needs adjustment to accommodate GHG and other attributed causes in the observed post 70s decrease.

At 1990 the gross observed shift in winter rainfall reduced it to 90% of 1925-75 mean (IOCI Climate Note NO 5/2004

GHG was assumed to have reduced it to 95 %, other anthropogenic (OA) effects to 98% of 95% and multi decadal variability (MDV) combined with OA to 94.5% of 95% (equivalent to MDV causing 30% of observed reduction)

As the GHG affected rainfall baseline further decreases the OA and MDV contributions were assumed to remain as a fixed proportion of the base rainfall. In some scenarios the MDV effect might disappear with time and this possibility is allowed to widen the uncertainty range.

Streamflow** (intermediate rainfall and west agricultural zone) at 1990 was 70% of 1925-75.

An approximate non-linear assumption was made relating streamflow to rainfall decrease for intermediate and agricultural zone catchments.
The assumption, discussed further in the text, is as follows -
10 % rain decrease ~ 67% flow, 20% rain decrease ~ 67% of 67% = 45% flow,
30 % rain decrease ~ 30% flow, 40% rain decrease ~ 20% flow

Table 2-4 Projected winter rainfall and streamflow changes
50 percentile ensemble range S/W

Projected change in intermediate and west agricultural zone** rainfall and streamflow development for the nominal A2#, B1# scenarios (50 percentile ensemble range)$^{(1)}$							
Element	Scenario	Change relative to	1990 as fraction of 1925-75	Scenario	Rainfall decrease coefficients$^{(1)}$ - adjustments to 1925-75 base		
					2030	2070	2100
Model estimates GHG effect only on winter rainfall ***relative to past***	A2	1925-75	GHG only coeff.$^{(3)}$ ~0.95 *See below* *GHG + OA + MDV =(~0.90)*	A2	(.89~.95) x.95 = .85~.90	(.74~.84)x.95 = .70~.80	(.665~.785)x.95 = .63~.75
	B1			B1	(.96-1.0)x.95 = .91~.95	(.83-.90)x.95 = .79~.86	(.81-.89)x.95 = .77~.85
Total winter rainfall ***relative to past*** *Assumed non GHG components of observed decrease (40%MDV)* *Combined with modelled GHG*	A2 + other anthropogenic only	1925-75	***Other anthropogenic +GHG coeff.$^{(3)}$ =*** *(~0.98)*GHG*	A2 +OA	98x(.85~.90) = .83~.88	.98x(.70~.80) = .69~.78	.98x(.63~.75) = .62~.74
	A2 +OA + multi decadal variability		***Other anthropogenic + MDV coeff.$^{(3)}$*** = *(~0.945)*GHG*	A2 +OA +MDV	45x(.85~.90) = .80~.85	.945x(.70~.80) = .66~.76	.945x(.63~.75) = .60~.71
	B1 + other anthropogenic only		***Other anthropogenic +GHG coeff.$^{(3)}$ =*** *(~0.98)*GHG*	B1 +OA	98x(.91~.95) = .89~.93	.98x. (.79~.86) = .77~.84	.98x(.77~.85) = .75~.83
	B1 +OA + multi decadal variability		***Other anthropogenic + MDV coeff.$^{(3)}$*** = *(~0.945)*GHG*	B1 +OA +MDV	45x(.91~.95) = .86~.90	.945x(.79~.86) = .75~.81	.945x(.77~.85) = .73~.80
Total % winter rainfall relative to past	A2 range	1925-75	~ 90% (observed)	A2#	80 ~ 88%	66 ~ 78%	60 ~ 74%
	B1 range			B1#	86 ~ 93%	75 ~ 84%	73 ~ 83%
	Range			Scenario range	80 ~ 93%	66 ~ 84%	60 ~ 83%
Total winter rain decrease from 1925-75	A2#	1925-75	~ 10% (observed)	% decrease	12~20%	22~34%	26~40%
	B1#			% decrease	7~14%	16~25%	17~27%
	Scenario range			% decrease	7~20%	16~34%	17~40%
Streamflow decrease from 1925-75	B1# – A2# scenario range rounded	1925-75	~ 30% (observed)	% decrease from 1925-75	22~55%	45~75%	50~80%

Assumptions

GHG rainfall decrease coefficients (50 percentile range of ensemble runs) are derived from multi-model studies by Charles (associated Tables). Their 1990 baseline needs adjustment to accommodate GHG and other causes in the observed post 70s decrease.

At 1990 the gross effect on winter rainfall was to reduce it to 90% of 1925-75 mean (IOCI Climate Note NO 5/2004

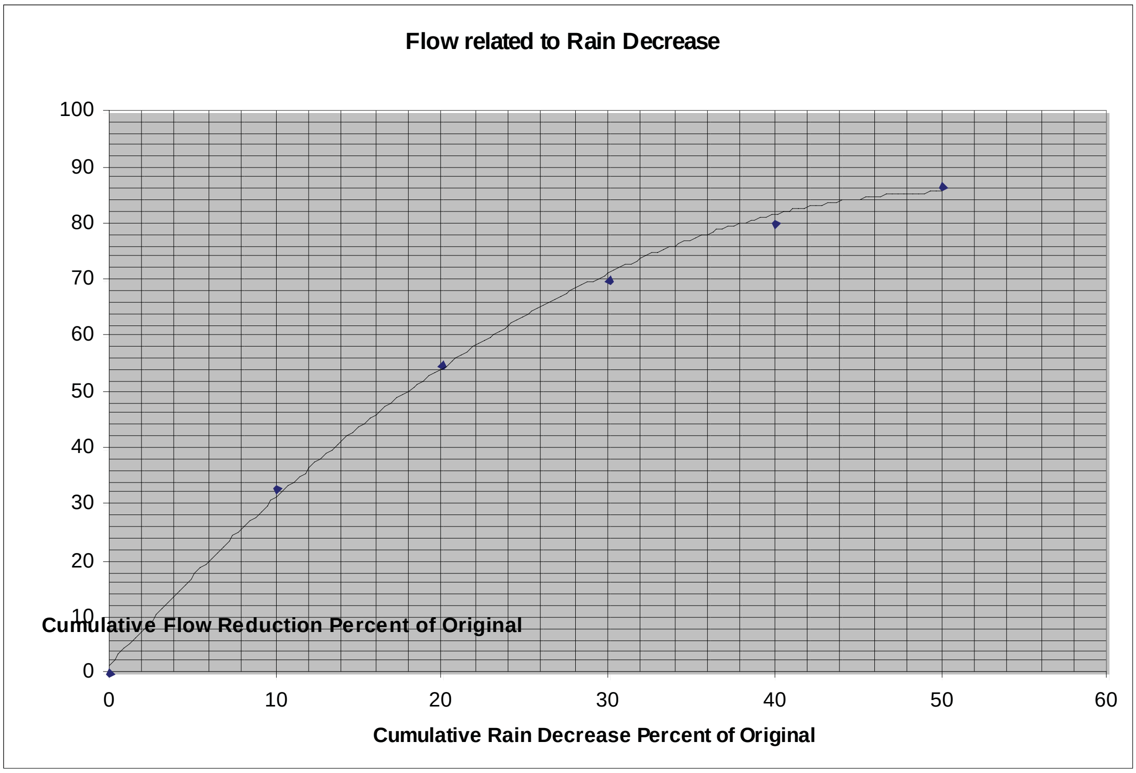
GHG reduced it to 95 %, other anthropogenic (OA) effects to 98% of 95% and multi decadal variability (MDV) combined with OA to 94.5% of 95% (equivalent to MDV causing 30% of observed reduction)

As the GHG affected rainfall baseline decreases the OA and MDV contributions remain as a fixed proportion of the base rainfall. In some scenarios the MDV effect might disappear with time. This occurs through the B2# scenario, when the A2# B1# Ranges are taken in the Table.

Streamflow** (intermediate rainfall and west agricultural zone) at 1990 was 70% of 1925-75.

An approximate non-linear assumption was made relating streamflow to rainfall decrease for intermediate and agricultural zone catchments.
The assumption, discussed further in the text, is as follows -
10 % rain decrease ~ 67% flow, 20% rain decrease ~ 67% of 67% = 45% flow,
30 % rain decrease ~ 30% flow, 40% rain decrease ~ 20% flow

Runoff calculations



Scenario	Rainfall decrease ranges and the corresponding runoff changes from above graph			
A2	50 percentile ensemble rain decrease	12~20%	22~34%	26~40%
	50 percentile ensemble flow as % of original	36~54%	58~76%	65~81%
B1	50 percentile ensemble rain decrease	7~14%	16~25%	17~27%
	50 percentile ensemble flow as % of original	23~42%	46~63%	48~66%
Range	50 percentile ensemble rain decrease	7~20	16~34	17~40
	50 percentile ensemble flow as % of original	23~54	46~76	48~81

Appendix 3:

Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)

The Storylines

Four different narrative storylines were developed to describe driving forces and their evolution and to add context for the scenario quantification. Each storyline represents different demographic, social, economic, technological, and environmental developments, which may be viewed positively by some people and negatively by others.

In each storyline a number of scenarios were developed covering a wide range of the driving forces of greenhouse gas (GHG) and sulphur emissions. All scenarios based on the same storyline form a scenario ‘family’.

The scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the UN Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol. However, GHG emissions are affected by non-climate change policies designed for a wide range of purposes. This influence is broadly reflected in the storylines and resultant scenarios.

A1 Storyline

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. *Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.*

The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis:

(1) fossil intensive (A1FI), (2) non-fossil energy sources (A1T), or (3) a balance (A1B) *across all sources (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).*

A2 Storyline

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1 Storyline

The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. *The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without* *additional climate initiatives.*

B2 Storyline

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. *While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.*

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

Interpreting the SRES A2, B1, A1B1 as markers for stabilisation scenarios

The selected scenarios are chosen as a band of realistic scenarios in outcome terms and which give access to a significant quantity of model analysis.

The highest, A2, is not a stabilisation scenario but in cumulative GHG emissions is less severe than the high growth (late stabilisation) extreme represented by A1F1. The 2070/2100 concentrations are a realistic upper bound marker reflective of global political weakness.

The B1 scenario as a lower bound marker is a mixture of optimism and realism. It is an aggressive and politically challenging stabilisation scenario, but short of the more ideal 450 ppm safe target level.

The A1B1 scenario is a useful middle-of-the-road scenario. It is useful as a marker for 2030 and mid-century outcomes because it more closely reflects the current rapid growth of global emissions.

A2 Nominal **1250 ppm** CO_2 equivalent by 2100

Politically weak: *The world fails to get its act together but, because of slow growth, the outcome is better than a business as usual extreme (e.g. A1F1) in the short or long-term.*

This is a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita **economic growth and technological change more fragmented** and slower than other storylines.

A1B Nominal **850 ppm** CO_2 equivalent stabilisation by 2100

Belated compromise: *After rapid business-as-usual growth the world achieves partial control consistent with human compromise, but the stabilisation level achieved falls well short of aspirations. This scenario with its rapid early emissions growth is nearest to current behaviour for short-term expectations*

This is a world of very rapid economic growth, global population that peaks in mid-century and declines thereafter. There is **rapid introduction of new and more efficient technologies**. *Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.*

This is a balanced scenario of alternative technological trends in energy. Neither fossil fuel intensive nor heavily reliant on non-fossil energy sources, A1B follows a **balance of measures with similar**

improvement rates in all supply and end use technologies. *The SRES scenario does not incorporate specific additional climate initiatives and its outcomes imply that the world community has not overlaid policies vigorously tied to minimising* CO_2 *accumulation*.

B1 Nominal **<u>550/600 ppm</u>** CO_2 equivalent stabilisation by 2100

<u>Strong response, short of aspirations:</u> *The world achieves outcomes consistent which contrasted with current action implies comparatively aggressive and early commitment to stabilisation. However, the stabilisation level achieved is short of the more aggressive 450 ppm target judged necessary to minimise dangerous risks.*

This is **a convergent world** with the same global population as in A1, that peaks in mid-century and declines thereafter. It has **rapid change in economic structures** toward a service and information economy, with reductions in material intensity and the **introduction of clean and resource efficient technologies.** *The* ***emphasis is on global solutions*** *to economic, social and environmental sustainability, including improved equity.*

This SRES scenario does not incorporate specific additional climate initiatives. However, ***consideration in stabilisation terms implies that the world community has acted early and aggressively*** *in a manner that causes* ***emissions growth to cease, return to present levels by 2030, and steadily fall to 50*** **per cent** ***of present by 2100.***

Appendix 4

Work File

Linear Interpolations of Sea Level Rise

Fremantle

Observed Sea Level Rise to 2000 from 1897 @ .0154m/decade

= (0.0154*10)m + (3* 0.0154)m = 0.154 + 0.0462 = 0.16m

Rise to 1990 = 0.16 – 0.0154 - 0.145

Global A2

Projected rise from 1990 to 2095 = 0.23 m to 0.51m

Per decade linear av rate = 0.0242 to 0.0537

Per 5 yrs (2095-2100) = 0.012 to 0.027

Per 25 yrs (2070-2095) = 0.061 to 0.141

Per 30 yrs (2000-2030) = 0.073 to 0.168

Linear Interpolations A2 Fremantle relative to 1897

2000	2030	2070	2095	2100
0.16			0.145 + 0.23 to 0.145 + 0.51 = **0.38 to 0.66**	
0.16	(0.16) + (0.073 to 0.168) = 0.233 to 0.328 = **0.23 to 0.33**	(0.38 to 0.66) – (0.061 to 0.141) = 0.319 to 0.519 = **0.32 to 0.52**	**0.38 to 0.66**	(0.38 to 0.66) + 0.012 to 0.027 = 0.392 to 0.687 = **0.4 to 0.7**
				Add acceleration component of 0.2 m
				0.6 to 0.9

Global B1

Projected rise from 1990 to 2095 = 0.18 m to 0.38m

Per decade linear av rate = 0.01894 to 0.04

Per 5 yrs (2095-2100) = 0.010 to 0.02

Per 25 yrs (2070-2095) = 0.047 to 0.10

Per 30 yrs (2000-2030) = 0.057 to 0.12

Linear Interpolations B1 Fremantle relative to 1897

2000	2030	2070	2095	2100
0.16			0.145 + 0.18 to 0.145 + 0.38 = **0.33 to 0.53**	
0.16	(0.16) + (0.06 to 0.12) = 0.22 to 0.28 = **0.22 to 0.28**	(0.33 to 0.53) – (0.05 to 0.10) = 0.28 to 0.43 = **0.28 to 0.43**	**0.33 to 0.53**	(0.33 to 0.53) + (0.01 to 0.02) = 0.34 to 0.55 = **0.35 to 0.55**
				Add acceleration component of ~ 0.15 m
				0.5 to 0.7

Appendix 5

Birds in the Swan Canning River System

The upper reaches of the two rivers (upstream of the Garret Road Bridge on the Swan River and upstream of Shelley Bridge on the Canning River) are weakly tidal, retain extensive fringing riparian vegetation and have associated wetlands in some areas. These upper reaches support a small number of ducks, cormorants and some other waterbirds, while the fringing vegetation is important for landbirds, in what is otherwise a largely urban landscape.

In contrast, the lower reaches of the rivers are consistently tidal and the shorelines have been modified, with large sections replaced with concrete retaining walls. The numbers of waterbirds in these lower reaches can be very high, particularly around Melville Water and the three reserves of the Swan Estuary Marine Park. Numbers are highest in summer, when counts of waders or shorebirds regularly exceed two thousand, and counts of ducks and swans regularly exceed five hundred. Cormorants can also be very abundant in these lower reaches, with counts of hundreds and even thousands. Although the shoreline in these lower reaches is generally modified, there are still areas of remnant vegetation, such as at Alfred Cove, that are important urban refuges for landbirds. The South Perth foreshore and its associated wetlands are important for waterbirds.

The use of the lower estuary by waterbirds has been recently studied to quantify the impacts of human disturbance (Bamford et al. 2003). Research has found that levels of use are highest in summer and are driven by tidal conditions. During low tides, waders and many other waterbirds forage on the tidal mudflats at Alfred Cove, roosting on the sandbars at Alfred Cove and the beaches of Milyu as the tide rises. Pelican Point, a former roosting site, is infrequently used due to high levels of disturbance. Some waders fly to the lakes of Rottnest Island to roost at night. Black Swans and, to some extent ducks, forage on the sea-grass (*Halophila sp.*) beds at Alfred Cove, and both swans and ducks rely on sources of freshwater such as drains at Alfred Cove and wetlands on the South Perth foreshore.

Waders require daily exposed mudflats to forage successfully. Consequently, the tidal nature of the Swan River, with periods of persistent high water levels results in very low numbers of waders. Regional conditions also affect the number of waders and waterbirds in the Swan and Canning rivers. The lakes of the surrounding Swan Coastal Plain provide alternative foraging and roosting habitat, but are often dry by mid-summer. In addition, cyclonic events in the arid zone can create alternative wetlands that attract waterbirds away from the coastal plain system.

Higher water levels, leading to stronger tidal influences upstream, reduced freshwater inflow (reduced rainfall) and increased temperatures are the key climate change impacts that will affect birds in the Swan and Canning rivers. Further, the effects of increased water levels and tidal influences will be enhanced by the reduced freshwater inflow. These climatic variations will result in changes in salinity levels, sedimentation, nutrient levels, vegetation, trophic structure of marine species, and pH levels. Further, changes in development patterns surrounding the rivers, as a consequence of both increased residential population and climate change, will impact the Swan and Canning river system birds.

Although increased sedimentation in the mid to upper estuary may lead to the creation of new tidal mudflats, a rise in sea level may see the decline of major tidal mudflats in the lower estuary. The Alfred Cove mudflats could potentially expand at the expense of samphire marshes. However, the area into which mudflats can expand is small comparative to the existing mudflat spatial extent.

Sedimentation is not expected to increase in the lower estuary so there is no reason to expect the existing mudflats to accrete and therefore maintain their current depth in relation to the rising sea level. This loss of mudflat will likely lead to an expansion of sea-grass beds, which will benefit the

Black Swan and some ducks but will negatively impact waders, notably the international migrants, for which the estuary is recognised as of significance.

The catastrophic loss of samphire marsh from the mid to lower estuary through the 1950s and 1960s is presumed to have led to the near disappearance of the Sharp-tailed Sandpiper. The samphire at Alfred Cove is used for foraging and roosting by some waders and ducks, particularly during very high water levels. It is likely that such sheltered roosts will be lost but may be replaced in the mid to upper estuary.

Waders and other waterbirds roost on the sandbars at Alfred Cove, and the beaches at Milyu and Pelican Point. During high tides, under existing conditions, these sites are lost and are therefore likely to disappear during moderate tides under conditions of higher sea level. This will impact ducks, swans, cormorants, pelicans and terns, as these species rely on secure roosts. It is not known how the sandbars at Alfred Cove will be affected by a rise in sea level.

Freshwater wetlands (e.g. South Perth foreshore and minor storm water drains that feed freshwater into the rivers) are important watering points for the Black Swan and some duck species. Under scenarios of increased salinity, the importance of these watering points will increase. Unfortunately, they are likely to be threatened by the rise in sea level.

Freshwater reaches of the rivers provide a drought refuge for waterbirds during summer and autumn. Whilst the number of waterbirds, especially ducks, is not very high, the value of these upper reaches as a drought refuge is likely to increase with declining rainfall because of the impact on nearby seasonal wetlands. The predicted decline in freshwater environments in the upper reaches under climate change scenarios is therefore of concern.

In the lower to mid estuary, fringing riparian vegetation and nearby upland vegetation will decline due to a rise in sea level and intrusion of salt water. In the upper reaches of the rivers, reduced freshwater flows will also result in a decline in fringing vegetation. In both areas, the decline will have greatest impact on landbirds, as this fringing and nearby vegetation is often the only environment remaining in an otherwise urban landscape. Of particular concern are areas where the fringing vegetation forms a wildlife corridor that may become fragmented due to the decline and death of shrubs and trees.

In the mid to upper estuary, a decline in water quality could lead to problems such as toxic algae and a decline in benthic invertebrates, which would adversely affect waterbirds.

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Caring for the Swan and Canning rivers