SUMMARY OF CLIMATE CHANGE RESEARCH REPORTS RELEVANT TO VICTORIA

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1. Introduction

This document provides a summary of the scope, key findings and current relevance of reports dealing with climate change scenarios, impacts, adaptations and vulnerabilities affecting Victoria. The focus is on major reports, most of which were funded by the State Government. They demonstrate the evolution over the past twelve years of climate change information available to the Government and other organisations to assist them in managing the possible impacts of climate change. All relevant reports are listed and summarised in chronological order (although grouped where relevant). In addition to such reports, there is a range of papers in the wider scientific literature that deals at least partly with potential climate change impacts in Victoria. Such work is cited as appropriate, but is separately summarised below only if it has a major focus on Victoria and is not covered in any of the reports.

2. General Climate Change Studies

Regional impact of the enhanced greenhouse effect on Victoria

Series of CSIRO reports to the EPA Victoria (1989-1992)

This series of annual reports were prepared by CSIRO as part of a multi-year contract with the EPA Victoria. The purpose of this research program was to provide an assessment of likely climate changes and impacts for the state. As there had been no previous assessment for Victoria, the scope of the work was broad. Relevant international developments in the science were reviewed, a range of global climate model results were analysed for the Victorian region and scenarios of climate change prepared, and an initial assessment of potential impacts in a number of areas was made.

The climate change information presented in these reports was obtained using climate models which are much less advanced and less realistic than the models in current use. In particular all of the results presented in this series of reports were obtained from global climate models (GCMs) which did not use a full ocean model ('a coupled model'). There have also been many other advances in our understanding of enhanced greenhouse climate change at the global and regional scale. Thus, as a source of climate change scenario information, these reports have been largely superseded by subsequent reports. However, the reports still contain valuable information on the sensitivity of some aspects of regional climate and climate change impacts to global warming, particularly as some impact areas have not been re-examined in any subsequent work. Such cases are highlighted in the summaries below.

1. Pittock and Hennessy (1989) *Regional impact of the greenhouse effect on Victoria. 1st annual report 1988-89.*

Scope of report: This report documented Australian region temperature changes under conditions of a doubling of atmospheric carbon dioxide based on global climate models. It also undertook a preliminary assessment of the implications of warming for changes in the frequency of extreme hot and cold days at a range of key centres in Victoria and for the amount of winter chilling (vernalisation) that is required for various horticultural crops.

Main findings: Decreases in the number of cold days and increases in the number of hot days were estimated for average warmings of 1 to 3°C. The analysis of changes in winter chill of various horticulture crops suggested that the viability of some crops would be threatened by a warming of 3°C.

Current relevance: The report is of little current relevance. However, the high sensitivity of extreme temperatures and winter chilling to small changes in average temperature remains largely valid.

2. Pittock and Whetton (1990) *Regional impact of the greenhouse effect on Victoria. Annual report 1989-90.*

Scope of report: This included a summary of international developments, an assessment of the performance of current global climate models at simulating Victorian climate, scenarios of change in temperature and rainfall by

2030 based on modelling and a paleoclimatic analogue, an enhanced assessment of impacts on extreme high temperature occurrence and on winter chilling, and an initial assessment of climate change impacts on snow cover and wheat yield.

Main findings: Based on scientific understanding at the time, the report indicated a regional warming of 1-3°C by 2030 relative to the 1980s and sea level rise of 10-50 cm by 2050. No clear scenario was given for rainfall change in Victoria due to disagreement between the main lines of evidence used, although it was noted that the CSIRO model suggested winter rainfall decreases for southern Victoria. The sensitivity of the occurrence of extreme temperatures (ie. very hot days) to moderate warmings (1-3°C) and the potential risks this posed to agriculture and horticulture were clearly established.

Current relevance: The results demonstrating the sensitivity of the occurrence of extreme temperatures at Victorian sites to warmings of 1, 2 and 3°C remain valid and the most detailed published.

3. Whetton et al. (1992a) *Regional impact of the enhanced greenhouse effect on Victoria. Annual report 1990-91.*

Scope of report: This included a summary of international developments, updated scenarios of climate change for Victoria, a first assessment of changes in extreme daily rainfall under enhanced greenhouse conditions using the output of the CSIRO GCM, and detailed modelling of climate change impacts on fire danger and wheat growth.

Main findings: Based on the latest science at the time, the report suggested a regional warming of 1-3°C by 2030 relative to 1990. Increases in summer rainfall in the north and east of the state and decreases in winter rainfall in the south and west were indicated but with low confidence. Increases in the intensity of the heaviest rainfall events were simulated by the CSIRO model. High resolution modelling indicated the potential for increased rainfall and higher winds associated with east coast lows (which affect eastern Victoria). Modelling studies of wheat grown under Victorian conditions gave the first indication that the positive effect of increased CO_2 may be counteracted by the effect of changes in climate and that the balance is sensitive to the cultivar used. The first study of the effects of climate change on fire occurrence indicated likely increases in fire danger in Victoria.

Current relevance: Most of the climate change results have received more detailed and more up-to-date treatment in subsequent reports and are thus of little current relevance. The east coast low modelling work which was reported in more detail in McInnes et al. (1992), indicated that east coast lows were likely to become more intense (i.e. lower central pressures, stronger winds and greater rainfall amounts and areal extents) under enhanced greenhouse conditions due to the increased sea surface temperatures. The study of Katzfey and McInnes (1996) supported this result by finding that the average intensities of east coast lows that occurred in an enhanced climate GCM simulation were on average, more intense than those in the control climate. While this result is likely to still be valid, the work needs to be updated by analysing the results from higher resolution coupled GCM simulations. The wheat modelling work remains a valid sensitivity study, although it should be considered alongside the later work of Wang (1995) and Howden et al. (1999) in which different aspects of the issue were emphasised. In the Australia-wide study of Howden et al. (1999), after allowing for adaptation, wheat production increased, except under scenarios where there were significant reductions in rainfall and average warmings of at least 2°C. The fire danger work has been extended by Williams et al. (2001) confirming the risk of increased fire danger, but work has not been undertaken using up-to-date scenarios.

4. Whetton et al. (1992b) *Regional impact of the enhanced greenhouse effect on Victoria. Annual report 1991-92.*

Scope of report: This report included a new assessment of changes in temperature and rainfall based on a range of GCM simulations, further analysis of extreme rainfall occurrence based on a CSIRO simulation, detailed modelling of impacts on snow cover and hydrology, and an initial assessment of impacts on pests and urban air pollution.

Main findings: The new GCM results continued to show rainfall increases in summer in the Victorian region and possible winter rainfall decreases. The effect on the occurrence of extreme temperatures of simulated changes in daily standard deviation of maximum and minimum temperature were found to be small relative to the effect of

changes in average temperature. The ability of high resolution nested regional models to provide more realistic simulations for the Victorian region was illustrated using a trial ten-year simulation. Modelling studies indicated strong sensitivity of natural snow cover in the Victorian Alps to increases in temperature. Average snow cover duration was projected to decrease from 140 days at present to 30-110 days by the year 2030. Modelling of the sensitivity of soil water deficit at two Victoria sites showed strong sensitivity to climate change with reductions in soil moisture likely in the future. Modelling results also indicated the potential for fruit fly to increase its abundance under warmer conditions.

Current relevance: The climate change results are of little current relevance as they have been superseded by results from more recent and more advanced modelling presented in later reports. The soil water deficit modelling study remains a useful sensitivity study for the locations studied, but should also be considered along with some more recent hydrological studies (see below). The snow modelling was superseded by a more detailed study (Haylock et al., 1994, see below).

Climate change scenarios for the Australian region

CSIRO (1992) *Climate change scenarios for the Australian region*

Scope of study: This document presented projected ranges of rainfall and temperature change for Australian region based on global warming scenarios of IPCC (Houghton et al. 1992) and the regional results of a range of GCMs. Qualitative assessment of some other aspects of climate change is also included.

Main findings: The report concluded that the Victorian region may warm by 0.5-2.0°C by 2030 and by 1-5°C by 2070. In summer, rainfall increases by 0 to +20% in 2030 and 0 by +40% in 2070. In winter, rainfall changes were uncertain, with projections of –10 to +10% in 2030 and –20 to +20% in 2070. Sea level was projected to rise by 5-35 cm by 2030 and 10-80 cm by 2070.

Current relevance: These scenarios have been superseded by CSIRO (1996) and the scenarios based on DARLAM given in Whetton et al. (2000c). These later scenarios point more strongly toward rainfall decrease.

CSIRO (1996) *Climate change scenarios for the Australian region*

Scope of study: This document presented updated projected ranges of rainfall and temperature change for Australian region based on new global warming scenarios of the IPCC (Houghton et al. 1996) and the regional results of a range of GCMs. Qualitative assessment of some other aspects of climate change is also included. It replaced the earlier Australia-wide scenarios of CSIRO (1992).

Main findings: The Victoria region may warm by 0.3-1.3°C by 2030 and by 0.6-3.4°C by 2070. In summer, rainfall may change by -4 to +8% in 2030 and by -10 to +20% in 2070. In winter, rainfall may change by -8 to +4% in 2030 and –20 to +10% in 2070. Sea level was projected to rise by 9-59 cm by 2070, which is much lower than the estimate given by CSIRO in 1992.

Current relevance: These scenarios are outdated, but new Australia-wide scenarios have not yet been released - a new release is planned in May 2001. Current science indicates that the projected warmings will be higher by 2070 and that there will be less tendency toward rainfall increase in summer. New scenarios will take into account the latest global warming projections of the IPCC (IPCC, 2001) and the latest climate model results.

The national and international perspective

Pittock and Hennessy, (1996) *The enhanced greenhouse effect: National and international developments*

Scope of study: The purpose of this report was to provide an updated assessment of national and international developments in climate change research. Topics covered included greenhouse gas emissions, sulphate aerosols, the

El Niño Southern Oscillation (ENSO), sea-level rise, observed trends and the detectability of climate change, and climate change scenarios for Australia. Some impact areas were also discussed.

Main findings: It was demonstrated that greenhouse gas emissions would have to be reduced to well below current levels in the next 30 to 100 years if atmospheric concentrations are to be stabilised at 2-3 times pre-industrial levels. The cooling effect of past and future increases in sulphate aerosols was shown to be important. Some new modelling results were cited which supported the likely increase in the intensity of heavy rainfall events under enhanced greenhouse conditions. The CSIRO (1992) climate scenarios were summarised. Model developments were described, and the need for high resolution regional modelling for use in local impact assessment was stressed. Impact research relating to ecosystems, agriculture, world food supply, pests and diseases and health were also discussed, but few new regional results were presented.

Current relevance: Although most of the science discussed is still valid, the material presented in this report has been superseded by that in subsequent IPCC reports (Houghton et al. 1996, Watson et al. 1998, Basher and Pittock 1998, IPCC Summaries for Policymakers on the world wide web).

Fine resolution assessment of enhanced greenhouse climate change in Victoria

Series of CSIRO reports to DNRE and EPA Victoria (1994-2000)

This series of annual reports was prepared by CSIRO for DNRE and (for the first report in the series) EPA Victoria. The purpose of this research program was to develop spatially-detailed scenarios of climate change over Victoria, based high resolution regional climate modelling. Victoria has a diversity of climatic regimes and potential for quite varied responses to enhanced greenhouse conditions, particularly with regard to precipitation. Such responses cannot be simulated by global climate models because of their coarse horizontal spatial resolution, but the potential existed for simulating this important detail with a high resolution regional climate model nested in the results of the global model. An outcome of the earlier EPA-funded series of CSIRO reports was a recognition of the need for such scenarios if impact assessment was to be well based.

The regional model of CSIRO Atmospheric Research ('DARLAM') was used for this purpose. However, regional modelling of climate was a new technique, and a multi-year program was required to develop an appropriate capability for the region. This work began in 1994/95 and ran through to 1998/99. Associated reports were published from 1997 onwards (with the last of the series yet to be published – see below). The reports were focused on scenarios of climate change, although hydrological impacts were considered in the final report.

1. Whetton et al. (1997) *Fine resolution assessment of enhanced greenhouse climate change in Victoria*

Scope of study: This report presented current climate and enhanced greenhouse results over Victoria from DARLAM nested in the CSIRO global climate model. Ten years were simulated for $1xCO_2$ (present CO_2 levels) and $2xCO_2$ (doubled CO_2) conditions at a resolution of 125 km. Scenarios of changes in mean maximum and minimum temperature and rainfall in 2030 were prepared.

Main findings: Precipitation and temperature over the Victorian region were found to be signficantly better simulated in DARLAM at 125 km resolution than in the GCM. A short trial simulation indicated that the simulation would probably be further improved at 60 km resolution. The simulated patterns of climate change (particularly rainfall change) differed significantly from those of the GCM. There was a predominance of rainfall decrease across Victoria in both models, but in DARLAM the southernmost areas showed rainfall increase. The scenario for 2030 gave warmings of 0.5 to 2.0°C and rainfall changes of 2-10%. The changes for 2070 were about twice as large.

Current relevance: Essentially all the results in this report have been superseded by those in subsequent reports and the report is now of little current relevance.

2. Whetton et al. (2000a) *Fine resolution assessment of enhanced greenhouse climate change in Victoria – Annual report 1996-97*

Scope of study: This report presented results similar to those of the previous report, but with DARLAM run at a finer horizontal resolution (60 km).

Main findings: Improvements in the spatial detail of DARLAM relative to the GCM led to improvements in the simulation of current climate. There were some remaining model biases (such as a tendency for rainfall to be too low in winter), and it was considered that these would be best addressed through other model improvements rather than finer resolution. The patterns of simulated climate change were similar to those presented in the previous report although the warming projected for 2030 was less (generally 0.4-1.4°C in 2030) as a result of using new IPCC global warming scenarios which incorporated the cooling effect of projected increases in sulphate aerosol emissions. In addition, the enhanced resolution of DARLAM led to a stronger tendency for rainfall increases in southern Victoria.

Current relevance: The results presented in this report are more comprehensive than any that have appeared in subsequent reports. Although there have been some further improvements in the quality of the DARLAM simulation, the general assessment presented in the report is still largely relevant. However, essentially all the climate change results in this report have been superseded by those in subsequent reports, and in this respect the report is of little current relevance. Note also that the results presented in this report were also published in Whetton et al. (2001a).

3. Whetton et al. (2000b) *Fine resolution assessment of enhanced greenhouse climate change in Victoria – Annual report 1997-98*

Scope of study: This report contained the first analysis of changes in climate variability and extremes as simulated in a high resolution model over Victoria. The report also examined the significance of projected changes against the background of natural climatic variability. The DARLAM simulation was similar to that used in the previous report, although it was extended to a twenty-year duration.

Main findings: The DARLAM simulation of current variability in temperature and precipitation over Victoria was reasonably good, although the model underestimated interannual rainfall variability, particularly in winter. The latter was attributed to the model being unable to represent natural variability associated with the El Niño-Southern Oscillation (ENSO). The changes in average precipitation and temperature were broadly similar to those presented in 1997. Simulated changes in temperature variability were generally insignificant, which confirmed that changes in extreme temperature can be estimated by applying a simple increase in mean temperature to observed daily data (as was done in some previous analyses). The DARLAM simulations also strongly support the results of earlier studies using GCMs that indicated marked increases in extreme daily rainfall events, implying an increase in flood frequency. It was also demonstrated that the simulated decrease in winter precipitation in northern Victoria for $2xCO_2$ conditions increased the frequency of dry winters in some areas by a factor of four. Up-dated climate change scenarios were prepared for 2030 and 2070. The high-case warming scenario for the second half of the 21st century represented a highly significant change in climate relative to current interannual variability. On the other hand, the low-case warming scenario for later in the 21st century may not be readily detectable where natural climatic variability is high, such as for summer maximum temperature in inland areas.

Current relevance: The current relevance of this report relates mainly to it being the first presentation of some new concepts and methods. In particular its discussion of variability and extremes, and how enhanced greenhouse climate change may be detectable against the background of natural variability, is still highly relevant. In general terms, many of the enhanced greenhouse results are current. However, the climate change scenarios were superseded by those presented in Whetton et al (2000c). The report also contains a valuable summary of some climate change impact studies of relevance to Victoria.

4. Whetton et al. (2000c) *Fine resolution assessment of enhanced greenhouse climate change in Victoria – Annual report 1997-98*

Scope of study: For this report, an updated version of DARLAM was nested in a new CSIRO GCM coupled to an ocean model. A realistic gradual increase in greenhouse gas concentrations was used in a 140-year simulation of climate from 1961-2100. This experiment represented a major step forwards in regional climate change research and is still the first of its type in the world. Changes in temperature and rainfall averages, variability and extremes over Victoria were described.

Main findings: The DARLAM simulation indicated a warming for Victoria of 0.5 to 2.2°C by 2050. The number of summer days over 35°C increased by 10 to 50% in the north-central and north-west and by 20-100% elsewhere. Winter days below 0°C declined in frequency by 10 to 60%. In the north, rainfall increased in summer and decreased in winter and spring. In the south, rainfall decreased in spring with little change in the other seasons. The number of spring droughts doubled throughout the state except in the southeast, and the number of wet summers doubled in the north. Extreme daily rainfall events became more intense and more frequent in many regions. The increase in the magnitude of the 1-in-20 year event was as large as 50% in some regions. The increased summer rainfall in northern Victoria, and the widespread rainfall decreases in spring, contrasted with the results of previous DARLAM simulations. The pattern of winter rainfall change (increases in the south, decreases in the north) was similar to previous results, although weaker. It was also noted that drier conditions (especially in winter) are more strongly evident in a number of other GCMs than in the CSIRO GCM. This suggested that if DARLAM was nested in other GCMs we may obtain drier enhanced greenhouse climates, thus placing the results of the DARLAM modelling nested in the CSIRO GCM towards the wetter end of conceivable results.

Current relevance: The simulation described in this report remains the most recent and relevant with regard to climate change over Victoria. As a high resolution regional climate simulation, it continues to be superior to that available for most parts of the world. However, there is a need to update the scenarios to allow for the latest projections of IPCC (2001), and to compare the results with those obtained in some of the most recent GCM experiments.

5. Whetton et al. (not yet published) *Fine resolution assessment of enhanced greenhouse climate change in Victoria – Annual report 1998-99*

Further study of the DARLAM simulation of Whetton et al (2000c) is being undertaken. This will include an assessment of climate change impacts on the State's water resources, including a focus on possible changes to the behaviour of the El Niño – Southern Oscillation (ENSO), potential evaporation and drought. Impacts on drought are also being assessed using the Australian Bureau of Meteorology definition for serious moisture deficiency.

The report is currently being finalised.

3. Specific Climate Impact Studies

Agriculture

Lottkowitz (1989) *The greenhouse scenario and Victorian agriculture.*

Scope of report: .Lottkowitz (1989) reviewed greenhouse gas contributions from agriculture, potential implications of CSIRO's climate change scenarios released in 1988, and possible response strategies.

Main findings: Victorian agriculture contributes to the greenhouse effect through methane from domesticated animals, carbon dioxide from land clearing and fossil fuel use, and nitrous oxide from fertilisers, but emissions could not be quantified. For annual crops and pastures, increased CO_2 temperature and rainfall could improve productivity, especially in winter. Pasture and livestock production systems should be able to cope with the rate of climate change. However, less winter chilling could severely affect the viability of current temperate fruit production. Management skills would need to adapt to counter shifts in the balance of pests, weeds and disease.

There would be increased summer cooling costs and lower winter heating costs. Increased erosion would stem from more intense rainfall. It was concluded that "in view of the uncertainty of current climatic predictions and demonstrated ability of farmers to adapt, specific incentives to adjust to the greenhouse effect are not being proposed at this stage. Provisions of the government's Rural Adjustment Scheme appear to be adequate for farmers". A Standing Committee on Agriculture initiated a national liaison group on the greenhouse effect.

Current relevance: Contributions from Victorian agriculture have been superseded by values in the 1995 State inventory at http://www.greenhouse.gov.au/inventory/inventory/stateinv/vic.html. The predicted reduction in rainfall in more recent reports means that the benefits for crops, pasture and livestock noted in Lottkowitz (1989) may not be realised. Qualitative impacts on heating and cooling remain valid. Additional qualitative impacts were identified in the 1993 CSIRO brochure on "Agriculture and greenhouse in south-eastern Australia" (see below). Impacts on fruit have been quantified by Hennessy and Clayton-Greene (1995) who found that a 1° C warming at Swan Hill and 3° C warming at Tatura would halve the number of years with sufficient chilling for stonefruit. Wang and Connor (1995) found that for current wheat varieties in Mildura, yield would increase by 10-30% for an increase in carbon dioxide from 350 ppm (1990 concentration) to 460 ppm, but yield would decrease by up to 50% for a warming of 3° C alone. Longer-season varieties were identified that maintain present yield variability or increase the average yield under warmer, higher carbon dioxide conditions.

CSIRO (1993) *Agriculture and greenhouse in south-eastern Australia.*

Scope of report: This colour brochure targeted at farmers and the general public summarises the enhanced greenhouse effect, contributions to greenhouse gas emissions from Australian agriculture, climate change scenarios for the year 2030, potential impacts on agriculture in south-east Australia, and how to reduce emissions.

Main findings: About one quarter of Australia's greenhouse gas emissions come from agriculture and forestry. CSIRO's 1992 climate change scenarios indicate warmings of 0.5 to 2.5° C by the year 2030, summers 0-20% wetter, more heavy downpours, and an uncertain rainfall change in winter (-10 to +10%). Impacts include more heat-stress and less cold-stress for cattle and sheep, less chilling for fruit leading to lower yield and quality, more problems caused by tropical and sub-tropical parasites such as cattle-tick, fewer problems from the tapeworm responsible for sheep measles, and reduced forage quality.

Current relevance: The emission estimates and climate change scenarios in this brochure are no longer relevant, but the impacts and mitigation strategies remain relevant. Emissions from Victorian agriculture have been superseded by values in the national 1999 inventory at http://www.greenhouse.gov.au/inventory/inventory/latest_inventory.html. The 1992 climate change scenarios for Victoria have been superseded by subsequent reports.

Coastal Studies

Black et al. (1990) *Prediction of extreme sea levels in northern Port Phillip Bay and the possible effect of a rise in mean sea level.*

Scope of Report: This study examined the meteorological conditions leading to extreme sea level events in Port Phillip Bay. Using a hydrodynamic model of both Bass Strait and Port Phillip Bay, it investigated the impact of several sea level rise scenarios on tidal amplitudes in Port Phillip Bay. It also examined the effect of sea level rise on wind setup in the Bay (the tendency for water levels to be greater at the downwind end of the bay relative to those at the upwind end).

Main Findings: The meteorological conditions that were found to contribute to extreme sea levels within the Bay were low barometric pressure and westerly winds associated with cold fronts. Rapid changes in wind direction such as those associated with the passage of cold fronts where prefrontal northerlies changed rapidly to postfrontal westerlies with the passage of the pressure trough were also found to contribute via the setting up of low frequency resonances (seiching) in the bay. Mean sea level rises of 0.1, 0.5 and 1.0 m were found to increase the tidal amplitude by 1%, 7% and 15% respectively. This result is attributed to the greater water depth caused by mean sea level rise over the entrance to Port Phillip Bay which reduces the frictional attenuation of tidal currents and enables the exchange of a greater volume of water between Bass Strait and Port Phillip Bay. Wind setup in the bay was

found to be reduced by about 3% when a 1 m sea level rise was imposed. This was attributed to the wind stress acting over a greater depth of water and hence producing smaller storm surge gradients.

Current Relevance: The analysis of extreme sea level events and the numerical modelling remains valid as long as the date of applicability of the sea level rise scenarios are revised in accordance with current estimates. Care is required in the interpretation of the wind setup finding. Wind setup is a tilting of the sea surface caused by locally experienced winds. However, the bulk of the sea level rise during a storm surge event may be caused by influences occurring over a greater scale than Port Phillip Bay as is indeed the case for events caused by frontal passage.

Crapper and Wood (1991) *The greenhouse effect: Impacts of a rising sea on Melbourne's tidal waterways and coastal environment*

Scope of Report: This study was carried out in conjunction with the previous study (Black et al. 1990). It investigated the impact of a 0.3 m sea level rise in combination with design tide levels currently adopted for planning purposes on inundation of northern Port Phillip Bay coastal areas. Vulnerable areas were identified on 1:2500 scale plans of the region.

Main Findings: The present design level of 1.6 m is already 0.3 m higher than the 1 in 100 year tide level of 1.3 m for northern Port Phillip Bay and so a safety margin of 0.3 m exists already. The present design level of 1.6 m would inundate 470 hectares of land and 700 residential properties. An increase in sea level of 0.3 m on this level would approximately double the area of land inundated and increase the number of threatened properties to 2400.

Current Relevance: This study is of current relevance as long as the sea level increase that was used is interpreted in the context of present sea level rise scenarios and locations of urban infrastructure has remained largely unchanged over the study region. More sophisticated methods for estimating inundation are now available using Geographic Information Systems (GIS). The improvement in accuracy that could be gained in repeating such a study depends on how much change to urban infrastructure has taken place in the study region over the past 10 years and the accuracy of the elevation data contained in the GIS (resolution greater than 1 m contours would be needed to improve upon this original study).

The Coastal Investigations Unit, (1992) *Victorian Coastal Vulnerability Study*

Scope of report: This report reviews the key issues of enhanced greenhouse climate change as they apply to the coast. It categorises the geology and geomorphology of the entire Victorian coast. These are addressed in four major sections including the Port Phillip Bay coast, the Western Port coast, the western Victorian coast and the eastern Victorian coast. Within each region, the coastline is further sub-divided into distinguishable sections for detailed categorisation of features such as geological origins, major oceanographic influences, ecological and anthropological characteristics. One-dimensional numerical modelling has been undertaken for a number of beach profiles to determine the likely impact of sea level rise scenarios of 0.3 m and 0.5 m on beach erosion. The scenarios are based on IPCC 1990 (Houghton et al., 1990) and are assumed to be valid for a 50 year planning horizon.

Main Findings: Low-lying land on the western side of Port Phillip Bay makes it potentially vulnerable to greenhouse changes due to significant impact of beach erosion, whereas there is considerable potential for damage to urban infrastructure through flooding on the highly-urbanised eastern side of the Bay. Low-lying marshland on large sections of the Western Port coastline are under threat of inundation in the event of greenhouse changes. Many areas of the western coastline of Victoria are potentially vulnerable to greenhouse changes due to fine grain size of beach sediment and high wave energy climate making these beaches prone to erosion. Many areas of the eastern coastline contain dune topography that may become increasingly mobile under greenhouse changes. Low-lying coastal land is also under threat of increased inundation. The modelling indicates that over the next 50 years, shoreline recession due to increased erosion is not likely to be great enough to reach the projected ultimate recession profile. In other words, the foreshore profile will not have reached equilibrium and will still be undergoing modification. However, on some beaches (in particular, those in Port Phillip Bay that are particularly narrow), the entire beach may have disappeared within this time frame.

Current Relevance: The categorisation of the Victorian coastline has current relevance assuming that no major engineering works have taken place in the interim period to significantly modify specific coastal locations. The sea level rise scenarios as applicable to the specified planning horizon are out of date. The modelling is somewhat limited in that it is one-dimensional and therefore does not take into account longshore sediment transport. Offshore reefs (where they exist) and current levels of erosion are not taken into account in the modelling. It also does not consider the impact on erosion of possible changed storm conditions.

McInnes and Hubbert (1996) *Extreme events and the impact of climate change on Victoria's coastline*

Scope of Report: This study examined the major causes of storm surges along Victoria's coast and examined how the meteorological forcing for such events may change with the enhanced greenhouse effect. High resolution numerical modelling of two recent storm surge events was undertaken over Bass Strait, Port Phillip Bay and at high horizontal resolution (approximately 50 m) over three low lying regions of Port Phillip Bay (Werribee, Hobsons Bay and Mordialloc). Simulations were repeated with an 0.8 m sea level rise imposed as well as a 10% increase in wind strength.

Main Outcomes: Westerly winds associated with cold frontal passage were the most common cause of storm surges along the south coast and these events strongly influenced sea levels within Port Phillip Bay. Analysis of changes in westerly wind events in available GCM simulations yielded inconsistent directions of change ranging from ±10% in frequency and intensity. Results of the detailed storm surge modelling highlighted areas vulnerable to inundation in each sub-region.

Current Relevance: The analysis of extreme sea level events and the numerical modelling remains valid as long as the date of applicability of the sea level rise scenario is revised in accordance with current estimates. The numerical modelling results largely complement those of Black et al. (1990). The earlier study focused on the tidal influences under sea level rise scenarios and the local and large scale meteorological forcing contributing to storm surges in the bay. McInnes and Hubbert on the other hand, focussed on the broader scale meteorological conditions that contributed to storm surge events along the southern coastline, the changes to which could be more readily analysed in the daily winds produced by GCM climate change experiments. This analysis of severe winds in GCM model experiments needs to be repeated in view of more sophisticated GCM model results being currently available. The high-resolution inundation modelling over the three sub-regions of Port Phillip Bay remains state-of-the-art (see for example, Hubbert and McInnes 1999a,b). However, modelling at this scale could be repeated in a risk assessment framework to produce return periods of tidal and wind driven sea levels under different climate change scenarios using methodologies that have been developed and applied elsewhere (e.g. McInnes et al., 2000).

Kay (1996) *Australian Coastal Vulnerability Assessment Project*

This report is a synthesis of nine projects carried out across Australia by various consultants to assess the vulnerability of selected areas of the coastal zone to climate change. The methodology used to assess vulnerability in each case was the Revised Methodology for Coastal Vulnerability Assessment (Kay and Waterman, 1993; Kay and Hay, 1993) which was devised to overcome some perceived problems of the IPCC Common Methodology for Assessing Vulnerability to Sea-level Rise (IPCC, 1991). It involves numerically scoring vulnerability and resilience of the coastal system to various internal and external stresses. Assessment is made for present and future conditions with the latter assuming (i) no change in current management regimes and (ii) an optimally modified management regime. The final outcome is a 'Sustainable Capacity Index' calculated for each case study area. Two case studies were carried out in Victoria, one in Port Phillip Bay which extended the study of McInnes and Hubbert (1996) and the other at selected sites in the Gippsland Lakes region.

Lawson and Treloar Pty. Ltd. (1995) *Vulnerability of coastal areas to climate change impacts – Trial of Revised Australian Methodology –Gippsland Lakes, Victoria*

Scope of Report: Two case study areas were chosen for assessment. These were Lakes Entrance township and Paynesville, Raymond Island and Eagle Point. Modelling included both flood inundation and shoreline recession modelling under a 0.3 m sea level rise scenario with increases in frequency and intensity of westerly winds and a decrease in frequency but increase in intensity of easterlies (east coast lows).

Main Findings: It was concluded that the natural shoreline areas would adapt to rising sea level and local economy would be largely unaffected. Increased flood frequency may affect tourism to the area. It was felt that community anxiety about perceived economic and environmental losses arising from sea level rise were more likely to create self-fulfilling social and economic change than the climate change itself if public education on climate change was not undertaken in a manner appropriate to reduce such concerns. Overall, defence and accommodation were seen as the most effective strategies against changing climate. The retreat strategy was not considered feasible.

Current Relevance: The conclusions relating to vulnerability of the case study areas may need to be revised as climate change research delivers more updated scenarios of future changes in storm frequency and intensity. Also, conclusions relating to shoreline adaptation may not hold under sea level rise scenarios that are more severe than 0.3 m.

Woodward-Clyde Pty. Ltd. (1995) *Vulnerability of coastal areas to climate change impacts – Trial of Revised Australian Methodology – Port Phillip Bay, Victoria*

Scope of Report: This study utilises the inundation modelling results of McInnes and Hubbert (1996) and the shoreline recession modelling results of the Victorian Coastal Vulnerability Study (Coastal Investigations Unit, 1992) for Port Phillip Bay as a basis for trialling the Revised Methodology. The modelled areas of inundation were incorporated into a GIS to determine areas of vulnerability.

Main Findings: The study identified many issues relating to the conceptual formulation and the application of the methodology that needed to be addressed. These included the need to develop sea-level rise and extreme event scenarios for time-scales appropriate to the relevant planning horizon (the scenarios used in McInnes and Hubbert, (1996) were worst case scenarios for 2070), and the need to select coastal regions that are uniformly characterised for a meaningful application of the numerical scoring of vulnerability and resilience. In terms of formulation, better definition of the components of the coastal system were needed, and greater clarity of the objectives. It was felt that the methodology had greater potential ability at the local than the national scale. In terms of the vulnerability assessment of the case study areas, in all three sites, the greatest vulnerability and lowest resilience related to the physical system due to increased inundation and erosion. This in turn increased the vulnerability of the flora and fauna of the areas. Negative economic consequences were also seen for each area relating a range of factors including a degradation of beach front amenity (e.g. Hobsons Bay and Mordialloc) or agricultural production (e.g. Werribee). It was felt that defence and accommodation were the most effective strategies against changing climate. The retreat strategy was generally not considered feasible.

Current Relevance: While the findings in relation to the use of the Revised Methodology remain relevant, the conclusions relating to vulnerability of the case study areas may need to be revised using up-to-date climate scenarios.

Human Health

Guest et al. (1999) *Climate and mortality in Australia. Retrospective study, 1979-1990, and predicted impacts in five major cities in 2030.*

Scope of study: Guest et al. (1999) quantified the relationship between climatic extremes and human mortality in the five largest Australian cities (Sydney, Melbourne, Brisbane, Perth and Adelaide) during the period 1979-1990. The relationship was then applied to a projected demographic change and a CSIRO climate change scenario, to predict potential impacts on deaths in the year 2030.

Main findings: With population growth and no climate change, climate-related deaths for those aged over 65 would number about 520 annually by the year 2030. With the added effect of climate change, death rates increase in summer and decrease in winter, with the net effect being a decrease of 10% over the five cities, and a decrease of 20-40% in Melbourne.

Current relevance: The relationship between climatic extremes and mortality remains valid. However, the climate change scenario (based on the CSIRO Mark 2 climate model scaled by the IPCC's 1992 global warming scenarios) will be superseded by those released by CSIRO in May 2001.

Snow-cover

Haylock et al. (1994) *Climate change and snow cover in the Victorian Alps*

Scope of study: This study used a model of snow-cover duration, an observed climate data set for the Victorian alpine area, and the CSIRO (1992) climate change scenarios to assess how changes in climate may affect natural snow cover in the Victorian Alps. Results were mapped across the Alps and given in more detail for selected sites.

Main findings: The model gave a reasonable simulation of observed snow conditions across the Victorian Alps. It demonstrated a very strong sensitivity of natural snow conditions to increases in temperature, although changes in precipitation also had an effect. A 1°C warming reduced the simulated duration at all sites and more than halved the duration at sites of lower elevation such as Mt Baw Baw. For a 3°C warming, simulated snowcover durations were near zero, even at sites with simulated durations as long 100 days under current climate. Very large increases in precipitation are required to compensate for the effect of a warming (e.g. a 50% increase is needed to compensate for 0.5°C warming at Mt Buller). Under a 'best case' scenario drawn from the CSIRO (1992) climate change scenarios, the decline in snow cover is not very pronounced, although by 2070 significant impacts are present at lower sites. Under a worst case scenario, snow cover duration at higher sites roughly halves by 2030 and approaches zero by 2070, and at lower sites approaches zero by 2030.

Current relevance: This report is still the most relevant available regarding the impact of climate change on natural snow cover in the Victorian Alps. Most of the results are presented in terms of sensitivity to broad ranges of climate change, and thus remain relevant. The results given for 2030 and 2070 are dependent on old climate change scenarios and are thus of less current relevance (although the scenarios of warming, the main driver of change in snow cover, have not changed greatly). A limited set of snow cover results were updated for the CSIRO (1996) scenarios by Whetton (1998) and slightly slower rates of snow cover decline were obtained. See also Whetton et al. (1996) and Koenig (1998).

Water Resources

Schreider et al. (1996, 1997 and 2000) *Potential impact of climate change on run-off and water availability for irrigation*

Scope of study: The possible impacts of climate change on water availability were assessed for the Goulburn, Kiewa, Ovens and upper Murray. The IHACRES rainfall-runoff model was used in conjunction with 'most wet' and 'most dry' climate change scenarios for the region prepared by CSIRO. The hydrological model needed to be modified so that it could simulate water run-off in areas affected by snow. The climate projections were drawn from CSIRO (1992).

Main findings: Under the most dry scenario, runoff volume across these catchments was reduced by 28 to 38% in 2030 and 53 to 64% in 2070. Under the most wet scenario the changes are small for the snow-free catchments (-3% to +4% in 2030 and 0% to +6% in 2070) but larger for the snow-affected catchments (7 to 11% increase in 2030 and 12 to 21% increase in 2070). Substantial increases in the frequency of high flows ('flood events') are simulated under the most wet scenario, and increases in drought events (based on soil wetness index) for the most dry scenario.

Current relevance: The study represents a valid sensitivity study for the catchments concerned under the modelling approach used. However, the scenarios are out-dated and the results given for 2030 and 2070 no longer apply to those dates. The range of rainfall changes do not capture the greater tendency toward drier conditions predicted in the latest climate change scenarios, suggesting that the results underestimate run-off decreases. The use in this study of changes in temperature as a proxy for changes in potential evaporation is a source of uncertainty. Scenarios for change in potential evaporation are now available and could be used in a subsequent study.

Wildlife

Bennett et al. (1991) ***The potential effect of the enhanced greenhouse climate change on selected Victorian Fauna***

Scope of study: This report examined the potential effects of climate change on the distribution of selected fauna of southeastern Australia and identified possible management implications. Six different scenarios of changes in temperature and rainfall were developed for the project based on advice from CSIRO (increases in temperature of 1, 2 and 3°C and various changes in rainfall). The effect of changes in climate on species distribution was determined using (i) current data on climate and species distribution and (ii) the bioclimatic analysis and prediction system known as 'BIOCLIM'. Maps of distribution change under various scenarios are shown for 42 species. The work is also summarised in Brereton et al. (1995).

Main findings: Nearly all of the species of fauna considered undergo reductions in range under the increased temperature. Fifteen species were predicted to have no suitable habitat in southeastern Australia under a 3°C warming. The responses to changes in rainfall varied amongst the species, with the most contracted range for some being the driest scenario and for others the wettest. On the basis of these results recommendations were made on how to enhance the current reserve system and on the need to possibly intensively manage threatened species.

Current relevance: This study remains highly relevant. However, although the six climate scenarios considered are within the plausible range for the later decades of this century, the results for these scenarios are best viewed as demonstrating sensitivity of species distribution to changes in climate. For projected changes in distribution by particular dates in the future, the results of the study would need to be re-interpreted with reference to the latest climate change scenarios.

4. Summary of the current status of relevant research

Research on climate change and its impacts in Victoria has proceeded in two phases over the past twelve years. The work in the early 1990's was broad in scope and provided an initial assessment of regional climate change using the modelling tools available and an initial assessment of impacts. Some impact areas, such as snow and coastal vulnerability, received more detailed attention. From the mid-1990's onwards research focused on developing more spatially-detailed scenarios of climate change. This work was successful and has developed an excellent database for in use in climate change impact studies. In this period, impact assessment received less attention, although hydrological impacts were considered.

In the late 1990's, CSIRO reports to the Victorian Government provided estimates of temperature and precipitation change and some assessment of hydrological impacts although these are in need of updating to take into account the latest climate modelling results. Other aspects of climate change and other impact areas have not been targeted. Therefore as the first step in a new research program there is a need to prepare a comprehensive assessment of our current knowledge of climate change and its impacts relevant to Victoria. It is this step that will occur in year one of the three year research program into climate change impacts and adaptation that is being funded by the Victorian Government.

During 2000-2001, the science of climate change has continued to evolve. There is a large range of global climate model experiments that have not been analysed for Victoria. Global climate modelling has continued to develop, and there are new global projections of future emissions of greenhouse gases. Now is an appropriate time to reassess the broad picture.

5. References

Basher, R.E. and Pittock, A.B. (1998): 'Australasia'. In Chapter 4 of *The regional Impacts of Climate Change: An assessment of Vulnerability,* Watson, R.T., Zinyowera, M.C., Moss, R.H. and Dokken, D.J. (eds). Cambridge University Press, New York, 517 pp.

Bennett, S., Brereton, R., Mansergh, I., Berwick, S., Sandiford, K. and Wellington, C. (1991): *The potential effect of the enhanced greenhouse climate change on selected Victorian fauna,* Arthur Rylah Institute for Environmental Research. Tech. Rep. 123. 224pp.

Black, K.P., Hatton, D.N. and Colman, R., (1990): Prediction of extreme sea levels in northern Port Phillip Bay and the possible effect of a rise in mean sea level. Report to the Board of Works by the Victorian Institute of Marine Science, VIMS, Melbourne.

Brereton, R., Bennet, S. and Mansergh, I. (1995): Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern Australia: A trend analysis. *Biological Conservation*, **72**, 339-354.

Coastal Investigations Unit, Port of Melbourne Authority, (1992): Victorian Coastal Vulnerability Study, EPA Victoria.

Crapper, G. and Wood, K., (1991): The greenhouse effect: Impacts of a rising sea on Melbourne's tidal waterways and coastal environment, Board of Works.

CSIRO (1992): Climate change scenarios for the Australian region, Climate Impact Group, CSIRO Divison of Atmospheric Research, Melbourne, 6 pp.

CSIRO (1993): Agriculture and greenhouse in south-eastern Australia. Brochure produced by CSIRO Division of Atmospheric Research for the Victorian Department of Conservation and Natural Resources and the Victorian Department of Agriculture, Melbourne, 6 pp.

CSIRO (1996): Climate change scenarios for the Australian region, Climate Impact Group, CSIRO Divison of Atmospheric Research, Melbourne, 8 pp.

Guest, C.S., Willson, K., Woodward, A.J., Hennessy, K.J., Kalkstein, L.S., Skinner, C. and McMichael, A.J. (1999): Climate and mortality in Australia. Retrospective study, 1979-1990, and predicted impacts in five major cities in 2030. *Climate Research,* **13**, 1-15.

Haylock, M.R., Whetton, P.H. and Desborough, C. (1994): *Climate change and snow cover duration in the Victorian Alps.* EPAV Publication No. 403, Environment Protection Authority Victoria, Melbourne, 45 pp.

Hennessy, K.J. and Clayton-Greene, K. (1995): Greenhouse warming and vernalisation of high-chill fruit in southern Australia, Climatic Change, 30(3), 327-348.

Houghton, J.T., Callander, B.A., and Varney, S.K. (eds) (1992): *Climate change 1992: The supplementary report to the IPCC scientific assessment, Working Group 1,* Cambridge University Press, Cambridge, 200 pp.

Houghton, J.T., Jenkins, G.J. and Ephraums, J.J. (eds) (1990): *Climate change. The IPCC scientific assessment*, Cambridge University Press, Cambridge, 365 pp.

Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Varney, S.K. (eds) (1996): *Climate change 1995: Contribution of Working Group 1 to the Second Assessment Report of the IPCC,* Cambridge University Press, Cambridge, 572 pp.

Howden, S. M., Reyenga, P.J. and Meinke, H., (1999): *Global change impacts on Australian wheat cropping.* Working Paper Series 99/04. CSIRO Wildlife and Ecology, Canberra, 121 pp.

Hubbert, G.D. and K.L. McInnes, (1999a): A storm surge inundation model for coastal planning and impact studies. *J. Coastal Research.* **15,** 168-185.

Hubbert, G.D. and K.L. McInnes, (1999b): *Modelling storm surges and coastal ocean flooding.* In: 'Modelling coastal sea processes', Ed. B.J. Noye, World Scientific Publishing Co., 159-187.

IPCC (2001): Climate Change 2000: The Science of Climate Change. Summary for Policymakers. www.unep.ch/ipcc/pub/spm22-01.pdf

IPCC Coastal Zone Management Subgroup (1991): *Common methodoloyg for assessing vulnerability to sea-level rise.* Ministry of Transport and Public Works, The Netherlands, The Hague.

Jones, R.N., (2000): Analysing the risk of climate change using an irrigation demand model. *Climate Res.* **14**, 89-100.

Katzfey, J. J. and K. L. McInnes, 1996: GCM simulations of eastern Australian cut-off lows., *J. Climate.*, **9,** 2337-2355.

Kay, R.C. (1996): *The Australian coastal vulnerability assessment project report.* Report to the Department of the environment, sports and territories by Environmental management services Pty. Ltd. 75pp.

Kay, R.C. and Hay, J. (1993): A decision support tool for coastal vulnerability and resilience assessment within integrated coastal zone management: An introduction. In McLean, R. and Mimura, N. (eds) *Vulnerability assessment to sea-level rise and coastal zone management*. Proceedings IPCC Eastern Hemisphere Workshop. Tsukuba, Japan. p237-48.

Kay, R.C. and Waterman P. (1993): Review of the applicability of the 'Common Methodology for Assessment of the Vulnerability to Sea-Level Rise' to the Australian Coastal Zone. In McLean, R. and Mimura, N. (eds) *Vulnerability assessment to sea-level rise and coastal zone management.* Proceedings IPCC Eastern Hemisphere Workshop. Tsukuba, Japan. p237-48.

Koenig, U., (1998): Tourism in a warmer world, Vol. 28. Geographisches Institut, Universitat Zurich, 229 pp.

Lawson and Treloar Pty Ltd, (1995): Vulnerability of coastal areas to climate change impacts – Trial of Revised Australian Methodology – Gippsland Lakes, Victoria. Report to Environment Protection Authority (Vic) by Lawson and Treloar Pty Ltd and Lodar and Bayly Consulting Group.

Lottkowitz, S. N. (ed) (1989): The greenhouse scenario and Victorian agriculture. Dept of Agriculture and Rural Affairs. Technical report Series No. 170. Melbourne, 24 pp.

McInnes, K. L. and Hubbert, G. D. (1996): Extreme events and the impact of climate change on Victoria's coastline. Report to the Environment Protection Authority (Vic) and Melbourne Water. CSIRO Division of Atmospheric Research and Global Environmental Modelling Systems. EPAV Publication No. 488. 69pp.

McInnes, K. L., L. M. Leslie and J. L. McBride, 1992: Numerical simulation of cut-off lows on the Australian east coat: Sensitivity to sea-surface temperature and implications for global warming., *Int. J. Clim*., **12,** 783-795.

McInnes, K. L., Walsh, K. J. E., and Pittock, A. B. (2000). Impact of sea level rise and storm surges on coastal resorts: a report for CSIRO Tourism Research: final report . Aspendale, Vic.: CSIRO Atmospheric Research. 17 pp.

Pittock, A.B. and Hennessy, K.J. (1989): *Regional Impact of the Greenhouse Effect on Victoria, 1st Annual Report 1988-89*, CSIRO Division of Atmospheric Research - Victorian Environment Protection Authority, Victorian Government Printer, 14 pp.

Pittock, A.B. and Hennessy, K.J. (1996): *The Enhanced Greenhouse Effect: National and International Developments*. A summary of national and international developments in climate change research reviewed for the Environment Protection Authority (Victoria). EPAV Publication 486, 47pp.

Pittock, A.B. and Whetton, P.H. (1990): *Regional Impact of the Greenhouse Effect on Victoria, Annual Report 1989-90*, CSIRO Division of Atmospheric Research - Victorian Environment Protection Authority, Victorian Government Printer, 70 pp.

Schreider, S.Y., Jakeman, A.J., Pittock, A.B. and Whetton, P.H. (1996): Estimation of possible climate change impacts on water availability, extreme flow events and soil moisture in the Goulburn and Ovens basins, Victoria. *Climatic Change*, **34**, 513-546.

Schreider, S.Y., Jakeman, A.J., Whetton, P.H. and Pittock, A.B. (1997): Estimation of climate impact on water availability and extreme flow events for snow-free and snow affected catchments of the Murray-Darling basin. *Aust. J. Water Res***., 2**, 35-46..

Schreider, S.Y., Smith, D.I. and Jakeman, (2000): Climate change impacts on urban flooding. *Climatic Change* **47**, 91-115.

Wang, Y.P. and Conner, D.J. (1995): Simulation of optimal development for spring wheat at two locations in southern Australia under present and changed climate conditions. *Agricultural and forest meteorology*. **79,** 9-28.

Waterman, P. (1996): *Australian coastal vulnerability assessment project report.* Report to Dept. Environment, Sport and Territories by Environmental Management Services Pty. Ltd. 75 pp.

Watson, R.T., Zinyowera, M.C., Moss, R.H. and Dokken, D.J. (1998): *Australasian impacts of climate change: An assessment of vulnerability.* Extracted from The regional Impacts of Climate Change: An assessment of Vulnerability. Panther Publishing and Printing, ACT, Australia. 96 pp.

Whetton, P.H. and Hennessy, K.J. (1994): *First Quarterly Report to the EPA Victoria on Fine Resolution Assessment of Enhanced Greenhouse Climate Change in Victoria*, CSIRO Division of Atmospheric Research, Melbourne

Whetton, P.H. and Hennessy, K.J. (in prep.): Future changes in climate extremes over Australia, *Climate Change Newsletter*.

Whetton, P.H., Fowler, A.M., Mitchell, C.D. and Pittock, A.B. (1992): *Regional Impact of the Enhanced Greenhouse Effect on Victoria, Annual Report 1990-91*, Victorian Office of the Environment, 68 pp.

Whetton, P.H., Hennessy, K.J. and Nicholls, N. (1999): BMRC-CAR collaboration on climate extremes. In *Annual BMRC-DAR Research Discussion Meeting: meeting report, Melbourne, Vic*. Bureau of Meteorology, p. 7.

Whetton, P.H., Hennessy, K.J., Katzfey, J.J., McGregor, J.L., Jones, R.N. and Nguyen, K. (2000c): *Fine Resolution Assessment of Enhanced Greenhouse Climate Change in Victoria: Annual Report 1997-98. Climate averages and variability based on a transient CO_2 simulation.* CSIRO Atmospheric Research consultancy report for Victorian Department of Natural Resources and Environment, 38 pp.

Whetton, P.H., Hennessy, K.J., Katzfey, J.J., McGregor, J.L., Jones, R.N. and Nguyen, K. (2001b): *Fine Resolution Assessment of Enhanced Greenhouse Climate Change in Victoria: Annual Report 1998-99.*

Whetton, P.H., Hennessy, K.J., Pittock, A.B., Fowler, A.M. and Mitchell, C.D. (1992): *Regional Impact of the Enhanced Greenhouse Effect on Victoria, Annual Report 1991-92,* Victorian Office of the Environment, 64 pp.

Whetton, P.H., Hennessy, K.J., Wu, X, McGregor, J.L., Katzfey, J.J., Nguyen, K., (2000a): *Fine Resolution Assessment of Enhanced Greenhouse Climate Change in Victoria - Annual Report 1995-96: Climate averages based on a doubled CO_2 simulation.* CSIRO consultancy report for the Victorian Department of Natural Resources and Environment, 43 pp.

Whetton, P.H., Katzfey, J.J., Hennessy, K.J., Wu, X., McGregor, J.L., Nguyen, K. (2001a): Developing scenarios of climate change for southeastern Australia: An example using regional climate model output. *Climate Research* (in press).

Whetton, P.H., Katzfey, J.J., Nguyen, K., McGregor, J.L., Page, C.M., Elliott, T.I. and Hennessy, K.J. (2000b): *Fine Resolution Assessment of Enhanced Greenhouse Climate Change in Victoria - Annual Report 1996-97: Climate averages and variability based on a transient CO_2 simulation.* CSIRO consultancy report for the Victorian Department of Natural Resources and Environment, 48 pp.

Whetton, P.H., Wu, X., McGregor, J.L., Katzfey, J.J., Nguyen, K. (1997): Fine resolution assessment of enhanced greenhouse climate change in Victoria, Contract report by CSIRO for Victorian Environment Protection Authority and Victorian Department of Natural Resources and Environment, EPAV Publication 574, 34 pp.

Williams, A.A.J., Karoly, D.J. and Tapper, N. (2001): The sensitivity of Australian fire danger to climate change *Climatic change (in press)*

Woodward-Clyde Pty Ltd, (1995): Vulnerability of coastal areas to climate change impacts – Trial of Revised Australian Methodology – Port Phillip Bay, Victoria. Report to Environment Protection Authority (Vic) by Woodward-Clyde and Victorian Institute of Marine Sciences.