Background report for the Adelaide Coastal Water Quality Improvement Plan

---

Report 6 **Understanding the possible impacts of climate change and population growth by the year 2030 on nearshore water quality of metropolitan Adelaide**

Understanding the possible impacts of climate change and population growth by the year 2030 on nearshore water quality of metropolitan Adelaide

A report to the South Australian Environment Protection Authority

Prepared by

Balance Carbon Pty Ltd

This report should be referenced as:

Cheshire, A.C., Moore, T. and Westphalen G. (2010). *Understanding the possible impacts of climate change and population growth by the year 2030 on nearshore water quality of metropolitan Adelaide*. Prepared by Balance Carbon Pty Ltd for the South Australian Environment Protection Authority. Jan, 2010.

Enquires should be directed to:
Matt Shorten, Managing Director,
Balance Carbon Pty Ltd
PO Box 3436 Rundle Mall
Adelaide, SA
5001

Phone: 1300 77 54 10
Fax: 08 8357 0360
Email: matt@balancecarbon.com

BalanceCarbon

Table of contents

List of tables

List of Figures

Acknowledgements

The authors would like to thank Planning SA, in particular Chris Rudd and Terry Bell, for their assistance in organising the population data used in this report. Shaun Thomas and Ying He from the EPA are thanked for their input in both running the model and explaining aspects of the output. Peter Pfennig and Linda-Marie McDowell from the EPA are thanked for their support in developing this project.

Abbreviations

ACWQIP	Adelaide Coastal Water Quality Improvement Plan
ACWS	Adelaide Coastal Waters Study
AMLR NRM	Adelaide and Mt Loft Ranges Natural Resource Management
ASR	Aquifer Storage and Recovery
CBD	Central Business District
CDOM	Coloured Dissolved Organic Matter
CEM	Coast, Estuarine and Marine
CO_2e	Carbon dioxide equivalents
DEH	Department of Environment and Heritage
DWLBC	Department of Water, Land and Biodiversity Conservation
EPA	Environment Protection Authority
EWS	Engineering and Water Supply
GIS	Geographic Information System
MCMF	Marine and Coastal Managers Forum
MERF	Monitoring, Evaluation and Reporting Framework
PIRSA	Primary Industries and Resources South Australia
Port Waterways WQIP	Port Waterways Water Quality Improvement Plan
TSS	Total Suspended Solids
WSUD	Water Sensitive Urban Design
WWTP	Wastewater Treatment Plant

1 Executive Overview

1.1 Background

Adelaide Coastal Waters represent a key environmental asset for South Australia. The quality of these waters provides for the maintenance of biodiversity and ecosystem integrity as well as supporting numerous human uses (ecosystem services) including recreation, waste disposal, commercial fishing and transport.

The purpose of the Adelaide Coastal Water Quality Improvement Plan (ACWQIP) developed by the South Australian Environment Protection Authority (EPA) is to establish baselines and targets for improvements in water quality over a 20 year timeframe based on the recommendations of the Adelaide Coastal Waters Study (ACWS; Fox *et al.* 2007).

This project was developed to better understand how population growth and climate change may impact upon natural stream flow, stormwater runoff and wastewater volumes and quality flowing into Adelaide's metropolitan coastal waters. This information will be used to support the development of targets and strategies for the ACWQIP.

1.2 Aims and objectives

This project was originally developed with the aim of assessing the impact of various population growth and climate change scenarios on water quality within Adelaide coastal waters. Subsequently the objectives of the project were revised when it was agreed in discussion between Balance Carbon and the EPA that the parameterisation of the catchment model (ACWS E2 Model) being used for this project was not sufficiently resolved to allow a meaningful analysis of the potential climate and population change impacts. On this basis the report has been revised to include:

- Historical context summarising impacts on Adelaide coastal water quality of past increases in the population of Adelaide paying particular attention to seagrass loss as an indicator of water quality decline;
- A review of the general implications for climate change in southern Australia, including a summary of currently available models;
- A summary of the projected population growth scenarios for Adelaide including the North, Central and Southern metropolitan regions;
- A critical analysis of the results obtained from the ACWS E2 model with particular reference to the need for more highly resolved parameterisation data with reference to both land use and population change; and
- A critical review of the modelling strategy with commentary and recommendations for what is required to develop an effective implementation of the model to assess the impacts from climate and population projections for the Adelaide metropolitan area.

1.3 Scope

This study reports on potential impacts on water quality for the Adelaide Coastal Waters region through a consideration of stormwater impacts and catchment management under a series of population growth and climate change scenarios. The scenarios used in this study focus on changes that could occur by the year 2030 which is a relevant timescale for management of coastal resources at the regional scale.

The study makes a number of assumptions including that there are no changes to management practices occurring "behind dam walls" in the catchments and storage infrastructure for potable water. The simple assumption is that there will be no more overtopping of dam walls or water storage reservoirs in the future compared to existing overflow levels, volumes and frequency.

It has been assumed that any discharges from industrial point sources will be reduced over time commensurate to achieving the *absolute* targets outlined by the ACWQIP and the ACWS (Fox *et al.* 2007). Absolute rates of reduction in WWTP and industry will therefore be achieved, regardless of the relative increases in demands from a growing population, or increases in growth related to industrial processes that produce nitrogen laden discharges to coastal waters.

Furthermore, a number of aspects related to climate change have not been considered including changes to sea surface temperature, ocean pH and sea level rise, all of which may impact or modulate other impacts. It is important to note that the modelling of such changes is not nearly as well represented in the literature as are other variables such as air temperature, rainfall and evapo-transpiration.

The scope and scale of these assumptions and proscriptions is such that there are real concerns as to the veracity of any model predictions, particularly as significant changes are expected in our approach to the management of potable water, stormwater and wastewater as components of broader water management strategies for the Adelaide region. A more detailed examination of these assumptions is presented in the discussion (see Section 7).

1.4 Approach

Originally the project was designed to use the ACWS E2 catchment model for Adelaide and associated catchments in order to predict the impact of climate and population change on stormwater discharges and thereby water quality in the Adelaide Coastal Waters region. This work was intended to inform the ongoing development of the ACWQIP.

After preliminary work using the ACWS E2 model to test the impact of a series of climate and population change variables (or possible future scenarios; as detailed in Section 6), it was found that the existing modelling framework, in particular the spatiotemporal scale of the input data, does not provide sufficient spatial resolution on important water quality issues. As a consequence, the authors lacked confidence that the modelling outputs produced were accurately reflecting the impacts of such changes on catchment condition and thereby inputs to coastal waters.

The approach was then revised to:

1. Provide an outline of likely climate and population change scenarios for the Adelaide region.
2. To use a small number of illustrative runs of the ACWS E2 model to highlight the potential effects of population and climate change on coastal water quality.
3. To critically review these outputs in the context of what additional work would be required to appropriately parameterise the model and thereby to provide advice on the work needed to allow for a more robust assessment of the impacts of climate and population change on coastal water quality.

In summary the current implementation of the ACWS E2 model is not an effective tool for investigating population and climate change scenarios, in part because of the limitations of the available input data, but also due to a range of issues within the model itself. The parameterisation data sets are poorly calibrated, provide only very coarse estimates of both

EMC and DWC contaminant generation, an assumption is made that these values are constant across the entire catchment and thereby there is little consideration of differences in land use or catchment condition. However, results of this study have clearly highlighted the requirements for moving forward and noted that substantial work is required in order to:

1. Provide spatially and functionally resolved estimates of contaminant generation;
2. Better define how climate will impact on contaminant generation through changes in land use, land condition, rainfall pattern and the likely influence of stormwater management;; and
3. Better define the land use changes associated with urban (re)development, industry and commercial development and the problems with indeterminate strategies for managing land supply; and.
4. Develop an improved input climate dataset that incorporates predictions with respect to temperature, humidity and rainfall changes, and an increase in the number of extreme weather events.

2 Background

Coastal development, waste and stormwater disposal, habitat degradation and overfishing are key human activities that have the capacity to negatively influence nearshore marine ecosystems (Fox 2006, Hobday *et al.* 2006, Turner *et al.* 2007). These influences are likely to be more noticeable in coastal areas of Australia because the majority of the Australian population is congregated in centres on the coast or river systems that drain to the sea (ABS 2006).

Loss of seagrasses from the Adelaide coast was first measured at the Glenelg Waste Water Treat Plant (WWTP) outfall and the Patawalonga outlet in 1968 (Shepherd 1970). The rate of seagrass decline has been variable, with peak rates occurring in the 1970s along the northern metropolitan coast (Hart 1997, EPA 1998). The area of seagrass loss is closely correlated with Adelaide's population (Figure 1) and it has been argued that this represents an integrated index of impact along the metropolitan coast. Although estimates vary, a range of reports have shown that between 4000 – 6000 ha of seagrass have been lost during the period 1949 - 2002 (EWS 1975, Shepherd *et al.* 1989, Steffensen *et al.* 1989, Hart 1997, EPA 1998, Cameron 2003, Westphalen *et al.* 2004).

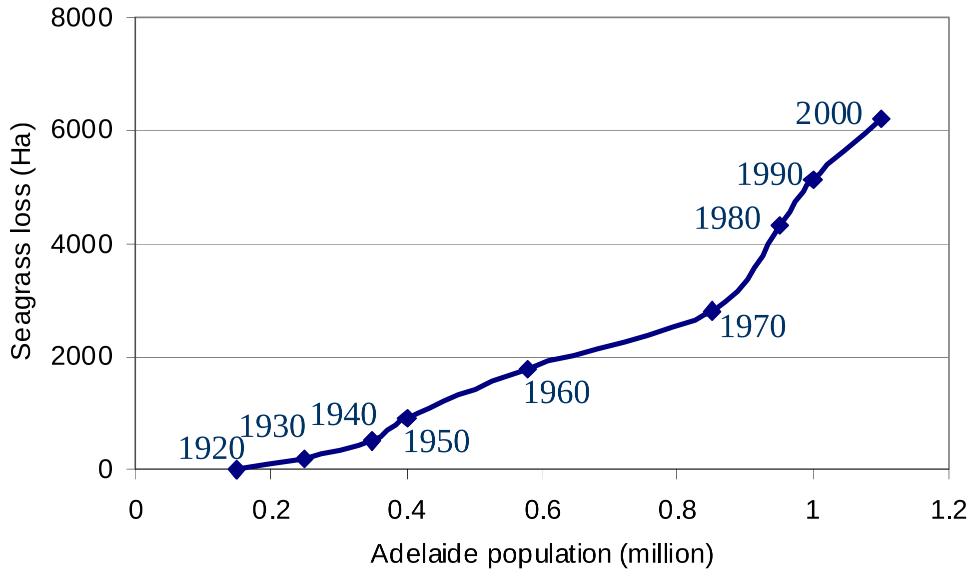

Figure 1 - Relationship between the population of metropolitan Adelaide and the area of seagrass loss (ha). Dates are shown on the plot for the period 1920 through to 2000. Note the acceleration of loss from 1970 onwards

Anecdotal and correlative evidence and the results of investigations into seagrass loss elsewhere suggested that declines in water quality, in particular the introduction of nutrients (chiefly nitrogen), were the primary cause for seagrass loss on the Adelaide coast. However, Adelaide's seagrass losses, which comprised predominantly *Posidonia* and *Amphibolis* spp., are unusual as they occur mostly in shallower areas, whereas the nutrient enrichment model for seagrass loss suggests that seagrass loss should progress from deeper areas (see Westphalen *et al.* 2004 for a comprehensive summary). The need to understand and therefore better manage the factors driving seagrass loss on the Adelaide metropolitan coast culminated with the initiation of ACWS from 2003 - 2007 (Fox *et al.* 2007). This multi-agency research program included four research oriented tasks focussing on seagrass loss, seabed stability and coastal water quality, including (Fox *et al.* 2007):

- Input studies – quality and quantity of terrigenous inputs to the nearshore region from wastewater treatment outfalls, stormwater inputs (including rivers and streams as well as pipes and drains), groundwater inputs and atmospheric deposition.
- Ecological processes – examining the effect of the above on seagrasses and key biota.
- Environmental information systems – seagrass mapping through remote sensing.
- Physical processes and modelling – included coastal sediment movements and physical oceanography.

Results of these investigations found that water quality decline was the primary cause for seagrass loss. High nitrogen and sediment loads as well as coloured water inputs have been identified as the cause for seagrass loss and degradation of coastal reef assemblages (Fox *et al.* 2007, Turner *et al.* 2007). The relationship between terrigenous inputs and seagrass loss and/or reef health decline is complex (Figure 2), but importantly, it can be seen that historical population increases have driven up inputs of stormwater and waste water with concomitant implications for nearshore water quality and, in turn, these impact directly on the health of coastal ecosystems.

It is the combined effects of a "business-as-usual" approach to catchment management and waste disposal that has led to coastal water quality decline and associated habitat degradation identified by the ACWS (Fox *et al.* 2007) and Reef Health surveys (e.g. Turner *et al.* 2007). These impacts on water quality and habitat are likely to be magnified as the human population of Adelaide continues to grow unless significant management interventions are undertaken. Additionally, it is probable that these existing effects will be exacerbated by changes to the climate as a result of global warming and ocean acidification.

The outcomes and recommendations of the ACWS have prompted or accelerated the development and implementation of policy, strategies and processes for improving water quality to Adelaide's coast. Chiefly these relate to (Fox *et al.* 2007);

- A 75% reduction in nitrogen load (relative to 2003 levels) and
- A 50% reduction in other pollutants (relative to 2003), in particular TSS and CDOM.

Recent drought and major concerns about the health of river systems, notably the Murray have further enhanced the need for development of improved water management (and particularly water security) strategies within South Australia and the Adelaide region. Similarly, the need to reduce the impact of land and water management practices is reflected in the Adelaide and Mt Lofty Ranges Natural Resource Management (AMLR NRM) Board's long term (20 year) regional targets for stormwater management (75% usage) and wastewater (100% reused; AMLR NRM 2008). SA Water has also implemented strategies targeted at reducing the volume and improving water quality from WWTP outfalls (SA Water, http://www.sawater.com.au/SAWater/Environment/SaveWater/EnvironmentImprovement Program/Recycled+Water+Overview.htm, accessed May 2009).

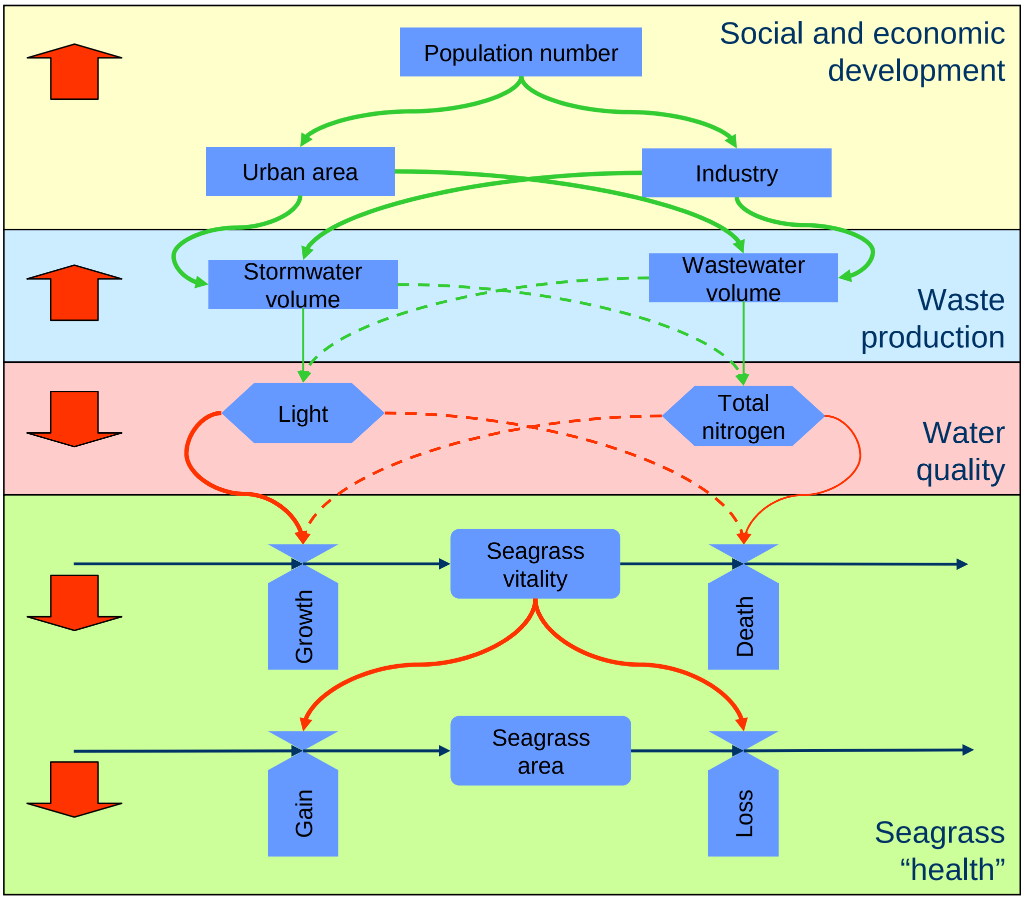

Figure 2 - Schematic showing the relationship between population increase and seagrass health. As population increases then so does the area allocated to urban and industrial/commercial development; this results in an increase in waste and storm water production, a decrease in water quality and a concomitant reduction in ecosystem health. A similar schema could be developed showing impacts on reef "health" or other coastal ecosystems.

These strategies include a range of integrated policy frameworks and programs that are generally aligned to 10 to 20-year delivery against targets, including;

- Waterproofing Adelaide – combines a broad range of strategies targeted at more efficient water capture, use and re-use (Government of South Australia 2005);
- AMLR NRM regional plan (AMLR NRM 2008);
- State Strategic Plan (Government of South Australia 2007);
- Adelaide Coastal Water Quality Improvement Plan (ACWQIP; EPA 2008).

The purpose of the ACWQIP developed by the EPA is to establish baselines and targets for improvements in water quality over a 20 year timeframe based on the recommendations of the ACWS (Fox *et al.* 2007). In simple terms, one could ask "what is the likely trajectory for coastal water quality associated with population change over the coming decades?" On the basis of past experience (for example, see Figure 2), it may be argued that unless active management of developments and catchments occurs in the future (compared to historical management failures), then the likely future scenario for coastal water quality and ecosystem health will see an acceleration of the existing problems (seagrass loss, degradation of reef health etc). Similarly, increases in South Australia's population to 2 million over the coming 20 years will likely result in further degradation of these coastal ecosystems (Figure 2).

On this basis, the development and implementation of the ACWQIP is an essential strategy to achieve an improvement in water quality along Adelaide's metropolitan coast, and thereby ensure there is not a continuation of the environmental damage witnessed over the preceding 70 years.

For the ACWQIP to be successful there is the need for a process of engagement with the major stakeholders, all of whom have critical roles to play in managing processes that lead to coastal environmental degradation. In addition to the SA EPA these stakeholders include;

- SA Water,
- Department of Environment and Heritage (DEH),
- Department of Water, Land and Biodiversity Conservation (DWLBC),
- Primary Industries and Resources South Australia (PIRSA), and
- Adelaide and Mt Lofty Ranges Natural Resource Management Board (AMLR NRM), with consideration of the desires for the region of the broader public.

Furthermore, given that the ACWQIP is aimed at medium to longer term targets (20 years or more), it's implementation and ongoing management must be sensitive to changes in background environment, in particular the potential impact of climate and population change. Significant changes to the population in urban and peri-urban settings, as well as changes to climatic conditions are expected within southern Australia and the Adelaide region over the coming decades. Such changes will have significant implications for the management of terrigenous inputs and coastal water quality.

3 Overview of the E2 Catchment Model Framework

The catchment model "E2" was developed by the CRC for Catchment Hydrology and its successor, the eWater CRC. This model was designed to report estimates of flow (amount of water) and constituents (sediments and nutrient concentrations) at any point within a river network over time (daily or sub-daily time steps). E2 has been subject to an ongoing process of modification and extension and now operates under the name "WaterCAST" (Water and Contamination Analysis and Simulation Tool; eWater CRC, http://www.toolkit.net.au/e2, accessed April 2009).

E2 was designed to allow users to construct whole of catchment models through selection and linking from a range of component models. E2 is not a model *per se*, but rather provides a framework within which a model can be constructed (Weber 2008). This framework can be applied to a broad range of catchment situations and questions. It is important to note, however, that E2 is also complex and requires a substantial level of understanding and experience on the part of the user with respect to integrated catchment modelling (eWater CRC, http://www.toolkit.net.au/e2, accessed April 2009).

Apart from the reliability and spatial resolution of the input data, the predictive power of E2 is a function of the constituent models to both the input data and the question being proposed (eWater CRC, http://www.toolkit.net.au/Tools/E2/features, accessed April 2009). Users must therefore understand the appropriateness or otherwise of the different constituent models to particular applications. Development of a model within this framework is thus often an iterative process wherein different combinations of models are applied, each requiring parameterisation and calibration against available data.

Despite the level of complexity within a fully developed model, the structural framework for E2 is based on three relatively simple components (eWater CRC, http://www.toolkit.net.au/Tools/E2/features, accessed April 2009):

- Subcatchments,
- Nodes and
- Links.

Subcatchments are the basic spatial unit within E2 (Weber 2008, eWater CRC, http://www.toolkit.net.au/e2, accessed April 2009) however subcatchments can be further sub-divided into their constituent 'functional units" which generally relate to different land uses (e.g. urban, peri-urban, rural, industrial, etc.) that are defined and parameterised by the user. Within each functional unit, there are three models (and associated sets of parameter values) that may be assigned:

- A rainfall runoff model,
- A constituent generation model and
- A filter model.

Nodes represent any point of interest within a catchment (subcatchment outlets, confluences, dams, gauges, etc.) and links form the connections between different nodes and therefore represent river systems, dams or floodplains. Within each link, three models may be employed:

- A routing model,
- A source/sink model, and

- A decay/enrichment model.

The constituent generation model essentially defines the contaminant loads that will be generated under both dry weather conditions and under rainfall events.

In the development of the model for the Adelaide Metropolitan area (the ACWS E2 model), Weber (2008) followed a seven step process;

1. Define/describe the spatial arrangement of the catchment and its streams.
2. Define a node-link network that represents the catchment.
3. Obtain data on Functional Units within each subcatchment. Functional Units typically comprise areas of land use that have similar characteristics in terms of water runoff and constituent (sediment and nutrient) generation. Functional units are defined by;
    a. Water runoff in response to rain events.
    b. Sediment and nutrient generation in response to rain events (Event Mean Concentrations - EMCs).
    c. Water runoff in the absence of rain.
    d. Sediment and nutrient generation in the absence of rain (Dry Weather Concentrations - DWCs).
    e. The total area of the functional unit within the subcatchment.

    Note that Functional Unit characteristics are fixed across all catchments.
4. Selection of component models that determine the behaviour of each Functional Unit/Node in response to weather events (both dry weather and rain). These models include the runoff generation model, constituent generation model and filtering options.
5. Further models related to routing and in stream processes are then used to link groups of models to describe the broader catchment.
6. Selection of climate data to be employed. Climate data may be for individual points or interpolated gridded data.
7. Parameterisation and calibration of all models through a process of comparing predicted outcomes (both flow and constituents) with measured levels.

The relationship between elements in the E2 model is illustrated schematically (Figure 3). This schema only attempts to represent a single node in the node-link model with the *Stream Inflow* process representing the link from any upstream nodes and the *Stream Outflow* process representing the link to any downstream nodes (or the receiving environment if this is the terminal node in the system). Note that *Land Class* represents the E2 Functional Unit, *DWC* the Dry Weather Concentration (constituent generation) and *EMC* the Event Mean Concentration (constituent generation). The *Runoff Library* represents the data on rainfall scenarios over long time series that is used to drive the *Runoff* and *Base Flow* processes for any given sub-catchment.

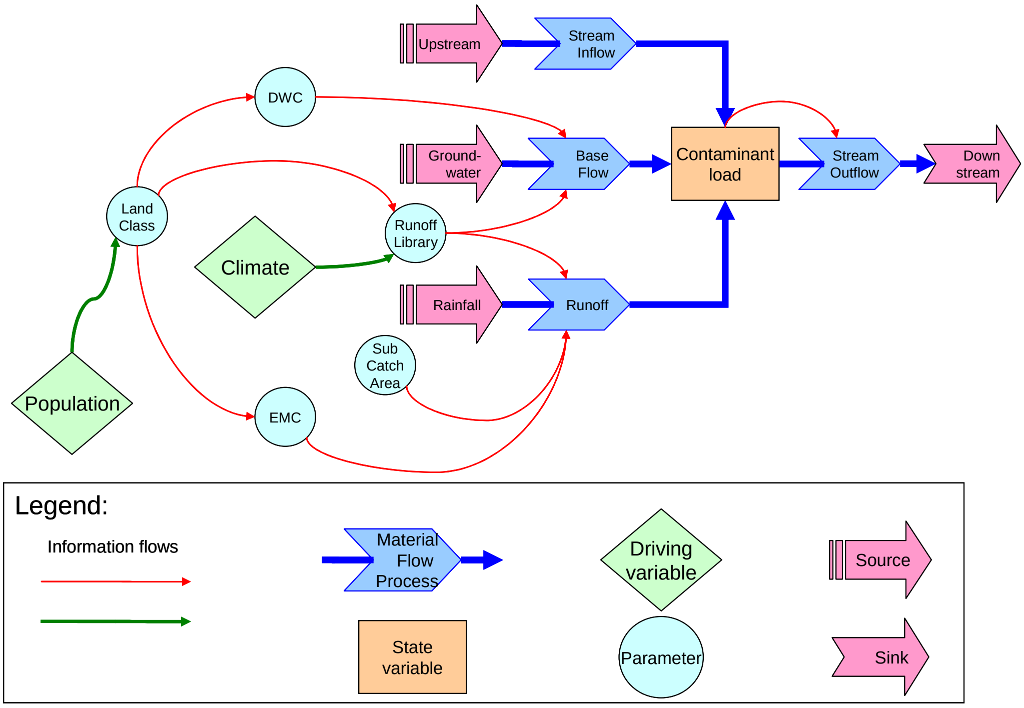

Figure 3 - Schema showing the relationship between various Population / Climate Change scenarios to runoff and contaminant concentration. The parameter labelled *Land Class* represents the "functional unit" defined in the E2 modelling framework. Red and green arrows show information flows in the ACWS E2 model implementation.

This representation of the model highlights the way in which Climate and Population are expected to influence contaminant loads being discharged to coastal waters. It should be noted however that climate, in particular, interacts in a much more complex way to modify parameter values in relation to Land Class (Functional unit), Dry Weather Concentration, Event Mean Concentration and Rainfall scenarios. The challenges in quantifying this complex interplay are discussed in detail in Section 6 (below) with recommendations for improvement detailed in Section 7.

It is important to note that the ACWS implementation of the E2 model (this project) only includes the control process shown as red and green arrows in Figure 3. In Figure 13 we have proposed a more sophisticated model framework in which the major effects of climate and/or population have been incorporated. The need for this revision is detailed in Sections 6 and 7 of this report and represents the major reason for changing the scope of the report from the original brief.

4 Climate change predictions for southern Australia

Climate change as defined by the Intergovernmental Panel on Climate Change (IPCC; CSIRO 2007) as:

> "a change in the state of the climate that can be identified by changes in the mean (and/or the variability), and that persists for an extended period, typically decades or longer".

The greenhouse gas (GHG) emissions caused by human activity has caused a "thickening" of the blanket of GHG's that would naturally have been in the atmosphere. This blanket of gases captures radiative heat from the sun inside the atmosphere where it normally would have been able to escape into space. This tends to lead to increasing temperatures: the greenhouse effect or global warming (Figure 4). As global temperatures rise, then there are likely to be significant changes to the range of "normal" conditions such as hot weather events, cloud cover, rainfall patterns, storm frequency and intensity as well as ocean currents. These abnormal meteorological and oceanographic conditions are collectively called climate change.

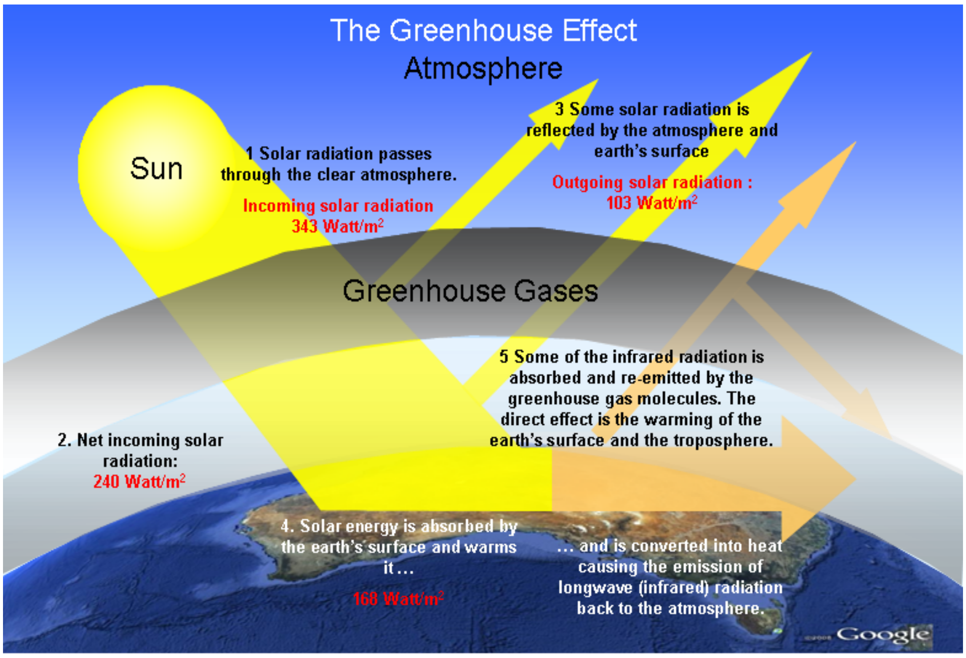

Figure 4 – Schematic of the greenhouse effect linkage to global warming. Adapted from the United Nations Environment Program GRID Ordinal using Google Maps as a base.

The IPCC Fourth Assessment Report (IPCC 2007) clearly states that evidence that global climate change is occurring is unequivocal. The IPCC (2007) also states that there is little uncertainty as to why climate change is occurring. Human caused emissions of the six "Kyoto Gases" (amongst others) have led to the enhanced greenhouse effect and subsequent climate change. While the global implications of climate change are becoming better understood, predictions of the effects of climate change at a regional or local scale are not as advanced as global models. However, organisations such as the CSIRO and the Australian Bureau of Meteorology have invested significant effort in developing models that predict the potential range of changes in temperature and rainfall intensity and timing that are likely to occur in the future as a result of climate change at a regional level.

For consideration of the effects of climate change relevant to the ACWQIP, several variables that are well reported in the relevant literature and that have the potential to influence the achievement of the ACWQIP were selected, focussing on rainfall and potential evaporation. A summary of these and other climate change related variables are discussed below. Not all were selected for incorporation into modelling scenarios, owing to a lack of numerical data that could be included from modelled predictions for the time step to 2030. The variables included comprise:

- Average temperatures
    - daily maximum,
    - daily minimum
    - seasonal changes in temperature
- Average annual rainfall
    - distribution and seasonality of rainfall
- Evaporation
- Drought
- Storm frequency and intensity

4.1 Average temperatures

The general trend, as would be expected under broad predictions for global warming induced climate change is for an increase in mean temperature which is consistent (Figure 5) with the observed changes over the last four decades.

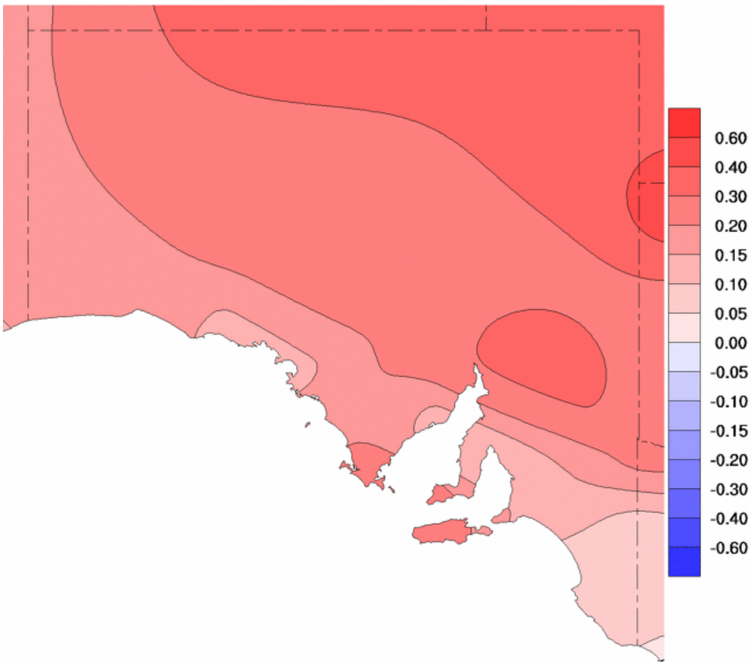

Figure 5 - Trend in mean temperature 1970-2008 – For most of South Australian there has been a trend for increases of between 0.05 to 0.2 ^{o}C per 10 years over the last 4 decades. This has been around 0.1 ^{o}C for the Adelaide region.

4.1.1 Daily maximum

The increase in the average daily maximum temperatures has implications for evaporation rates and evapo-transpiration (moisture loss from vegetation) rates. As average temperatures increase, generally the rate of evaporation from any uncovered surface waters increases. This will cause a reduction of flows through the catchments to the coast. Also, as evapo-transpiration rates increase, there will be an increased draw on sub-surface waters by existing non-irrigated vegetation as plants seek to maintain their internal water balance. This may lead to a reduction in flows of subsurface waters that either feed freshwater seeps, or inflows to surface water bodies. A decrease in groundwater availability and reductions in soil moisture from increased evaporation may lead to an increased demand for irrigation. Ineffective irrigation and catchment management practices can lead to the flushing of sediments and excess nutrients into waterways.

4.1.2 Daily minimum

The predicted general decrease in the number of cold nights may have implications for frosts. Frost events are generally widespread in the Adelaide metropolitan region, especially on the elevated areas of the Mt Lofty Ranges. However, frost does not contribute a significant level of precipitation other than to surface moisture levels. The decreasing frequency of these events will lead to lower soil moisture levels throughout the cooler months. This may lead to further demand on sub-surface water sources for natural systems and increased need for irrigation for managed land and vegetation types..

4.1.3 Seasonal changes in temperature

Along with the overall annual warming indicated above, warmer temperatures are very likely to be apparent in all seasons.

4.2 Average annual rainfall

The CSIRO (2007) predictions for average annual rainfall for 2030 include both dramatic decreases and moderate increases. This discrepancy between model outcomes makes prediction of rainfall changes more difficult, although the median model output (best estimate – see below) suggests a decrease in annual average rainfall. Decadal variability may enhance or mask changes in rainfall patterns (CSIRO 2007). The observed changes over the last four decades (CSIRO 2007) suggest a reduction in rainfall across South Australia of between 5 and 50 mm per ten years (Figure 6).

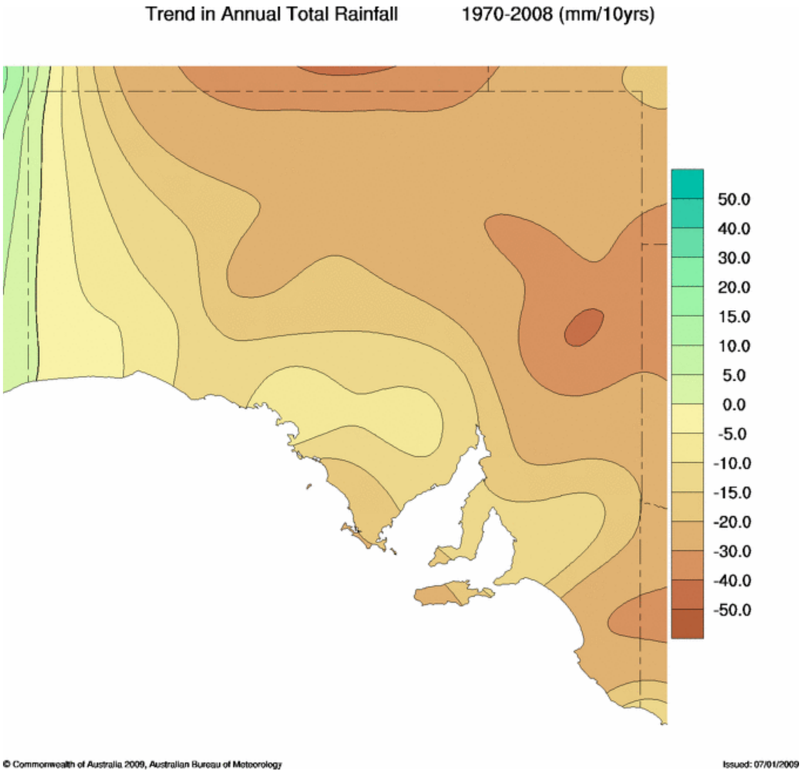

Figure 6 - Trend in total annual rainfall 1970-2008 – For most of South Australia there has been a decreasing trend of between 5 to 50 mm per 10 years over the last 4 decades. This has been around 10 mm for the Adelaide region.

4.2.1 Distribution and seasonality of rainfall

Geographic and temporal distribution of rainfall is expected to continue to change in south eastern Australia (Timbal *et al.* 2007). The Sub-Tropical Ridge (STR) is a naturally occurring pressure gradient that extends in a general east to west band across southern Australia, roughly from Adelaide to Canberra. The STR has intensified in recent years in close correlation with increasing mean temperatures as a result of global warming. Along with the intensification of the STR, there is also a negative correlation between mean sea level pressure and mean rainfall. In short, the STR creates a north-south boundary, which has seen lower rainfalls in south eastern Australia (including the Adelaide region) during the autumn and winter period with increasing prevalence of large, slow moving high pressure systems over Adelaide, and lower rainfall in the north of South Australia during the summer and autumn period. The rainfall deficit seen in south-eastern Australia since the 1990's (Figure 6), including the Adelaide region is therefore considered likely to represent a step change in climate that is directly linked to global warming. If this prognosis of an intensification of the STR leading to a reduction in rainfall on the land area to the south of the STR, then it is likely that rather than more drought conditions occurring, the ongoing lack of rainfall will effectively put that land area under semi-permanent drought conditions.

4.3 Evaporation

The effect of higher temperatures is an increase in the capacity of the air to hold more water vapour (i.e. increased evaporation potential). As the expected increases in air temperature at sea level occur, the air can carry more water vapour, thus it is likely that the relative humidity of the air will increase, by -1.5% to no change by 2030 for Adelaide (CSIRO 2007). As global warming proceeds, the warmer air will draw more moisture into the air as water vapour, drying soils and removing volume from water bodies in the catchments.

4.4 Drought

The CSIRO (2007) predictions for drought (defined as a prolonged period of low soil moisture, with the capacity to constrain agricultural production) shows that it is likely for drought conditions to increase by around 20% compared to the period 1974-2003.

4.5 Storm frequency and intensity

For the Adelaide region, the CSIRO predictions are for a general reduction in the number of severe wind storm events during the cool months of May through October. The passage of deep low pressure systems crossing the Adelaide region will become less frequent as global warming accentuates the presence of the Sub Tropical Ridge and the Southern Annular Mode (winter westerly wind system), and increases the likelihood of large, slow moving high pressure systems across south West Australia during the cool months. This will result in potentially fewer storms, lower winter storm wind speed (especially from the west quadrant) and less occurrences of large hail.

4.6 Climate Change Scenarios for South Australia

For climate change scenarios, CSIRO (2007) "Climate Change in Australia" predictions were employed as they were seen to be the most up to date publicly available models for South Australia at this time. The model selected to infer climate changes for 2030 was the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A1B model (see CSIRO 2007; Figure 7).

The SRES A1B model has basic assumptions regarding economic, policy and social shifts towards a balance between fossil fuel and clean energy production leading to a global atmospheric carbon dioxide equivalents (CO_2e) concentration of 720 parts per million (ppm) by the year 2100 (Figure 7), which is more than double the 1990 level of 352 ppm (Meehl *et al.* 2007 in CSIRO 2007). Intrinsic in this assumption is a decrease in fossil oil consumption past 2050, with a greater balance between renewable and non-renewable fuel types by this time.

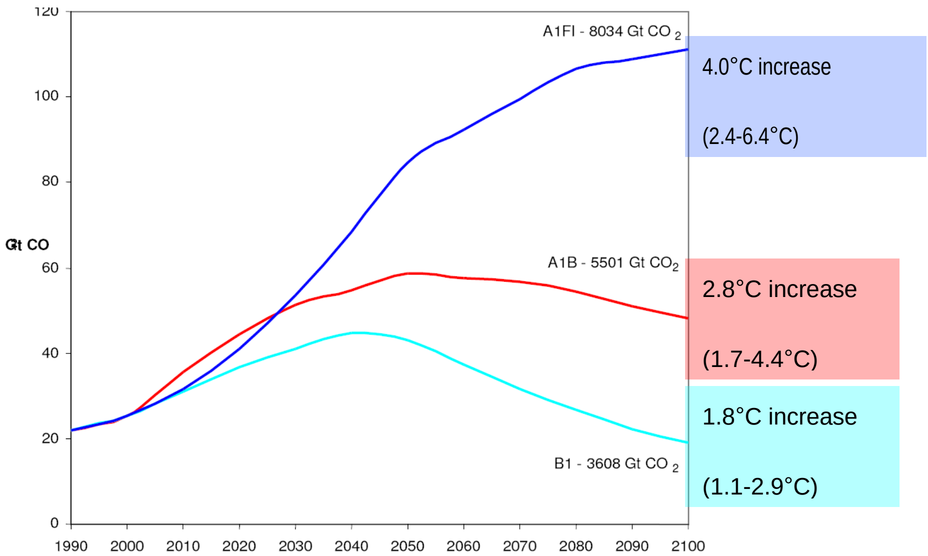

Figure 7 - IPCC projected cumulative growth in global GHG emissions over the next century to 2100, measured as gigatonnes CO_2e. The best accepted model at the time of release (SRES) was A1B. Figure modified from Garnaut 2008 and IPCC 2007 Table SPM-3.

Specific changes in climate predicted under the SRES A1B model for Adelaide in 2030 (Table 1) range from the 90th percentile model outputs, the median or best estimate (where most models agree with the outcome) and 10th percentile model outputs. The year 2030 was chosen as it is a point at which there are reasonable predictions available for both population and climate change, and is within a timeframe relevant to the development and management of policies to protect and enhance environmental values such as the ACWQIP and AMLR NRM plans. However, it should be noted that the current rate of emission growth align with the A1F1 (or most pessimistic emissions growth) scenario, and looks increasingly unlikely to move towards the emissions predicted at by the A1B scenario. The A1F1 scenario assumes that GHG emissions will continue to grow unabated, with no limits on emissions into the future. A1B and B1 both assume successful controls and new technological developments are put in place to reduce rates of GHG emissions by 2050. Shaded boxes (Figure 7) present the predicted global temperature increase (relative to the period 1980-1999) by 2100 with the likely range of temperature increase in brackets.

For climate change scenarios, the underlying data in the E2 model were extracted, and the prediction for climate change impact was applied to the summed data at both a seasonal and annual level. The SILO (see Weber 2008) input data in the E2 model ran from 1987 to 2007. The CSIRO modelling of climate change used Australian data over the period 1980 to 1999 to determine the base condition and % change of the relevant climate variables. As such, it was necessary to truncate the SILO input data at year 1999. Truncation of the data set may lead to some discrepancies in the final model outputs relative to the CSIRO predictions. As such, model outputs should be interpreted to represent the range of likely outcomes, rather than an explicit statement of absolute environmental conditions at 2030.

It also needs to be acknowledged that key elements of climate change prediction for southern Australia, notably an increase in extreme weather events were not incorporated within the input dataset.

Table 1 - Climate change scenarios for the Adelaide metropolitan region using SRES A1B scenario based modelling of climate change conditions (relative to 1990 levels) by 2030. Climate change data presented are taken from CSIRO, 2007 using the 10th, median model predictions ("best estimate"; CSIRO 2007) and 90th percentile outcomes for each climate variable. Values represent the range of outcomes from 23 independent climate models (CSIRO 2007), and show the lower, mid and upper ranges of the independent model predictions.

		Climate change scenarios		
Indicator	**Season**	**90th Percentile**	**Median ("best estimate")**	**10th Percentile**
Temperature	**Annual**	**+1.3**	**+0.9**	**+0.6**
(° C)	Summer	+1.4	+0.9	+0.6
	Autumn	+1.3	+0.9	+0.6
	Winter	+1.2	+0.8	+0.5
	Spring	+1.3	+0.9	+0.6
Rainfall	**Annual**	**+2**	**-4**	**-11**
(%)	Summer	+11	-2	-14
	Autumn	+9	-1	-11
	Winter	+2	-6	-15
	Spring	+3	-8	-19
PET Evaporation	**Annual**	**+4**	**+2**	**0**
(%)	Summer	+5	+2	0
	Autumn	+5	+3	+1
	Winter	+12	+5	+1
	Spring	+3	+1	-1

The model outputs detailed in Section 6 of this report use these three climate change scenarios (Table 1) along with the base case (current climate).

5 Predictions for population change

South Australia's population in 2006 was 1.56 million, increasing to 1.58 million in 2007 (ABS 2008). The South Australian Strategic Plan (updated 2007) sets a series of very specific targets for population change in South Australia for 2050. In particular, the plan sets a target to:

> "Increase South Australia's population to 2 million by 2050, rather than the projected population decline" (Target 1.7).

The Strategic Plan also calls to:

> "Maintain and develop viable regional populations levels for sustainable communities" (Target 5.8).

Given the trend for rural communities to lose residents to larger cities, it is probable that policy frameworks will be put in place to encourage some of the projected growth to move into country centres. However, the bulk of the population density will remain in the greater Adelaide region consistent with the distribution pattern in 2006 (Figure 8).

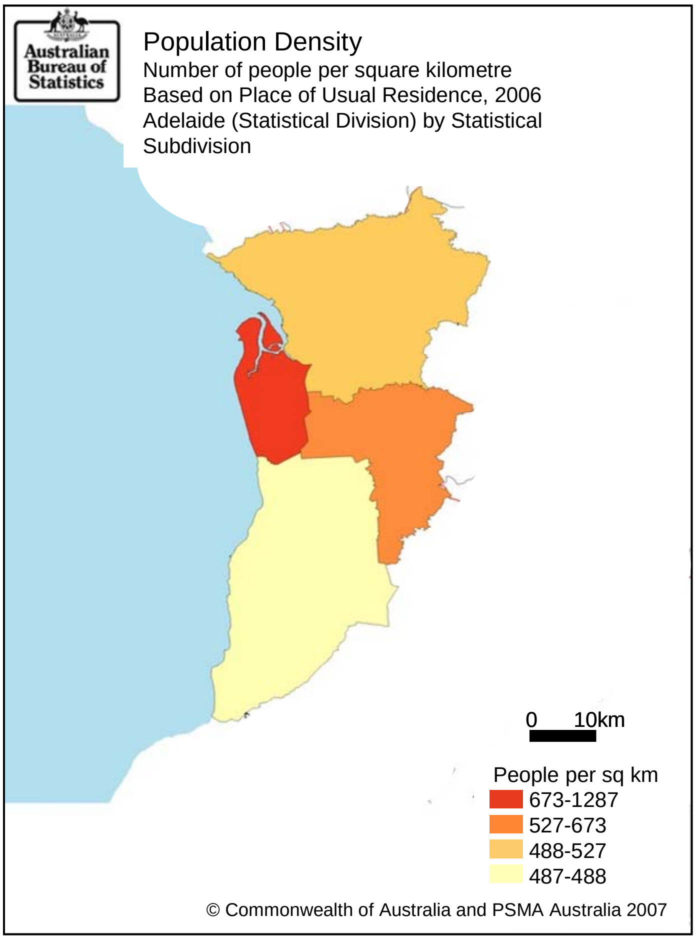

Figure 8 - Population density distribution for South Australia in 2006. Source: 2006 Census MapStats: South Australia.

Planning SA is currently (at the time of writing) reviewing population growth projections for the State in the development of the Greater Adelaide Plan. While data are not available in the public domain, Planning SA have provided some indications about the likely demand for new dwellings and how this could be satisfied given a mixture of new land supply and densification (in-fill) of existing developments. While a variety of scenarios have been made available by Planning SA, discussions with the EPA resolved that this exercise should only consider the high-growth scenario which is considered most likely under current circumstances. The high-growth scenario assumes that there will be a more rapid population increase caused by policy frameworks such as the designation of SA as a “regional centre” for immigration purposes, allowing for the preferential intake of international migrants to the State.

The projections supplied by Planning SA were based on land availability in the greater Adelaide region. Data were extracted from the Planning SA GIS database, referenced to the catchment areas used in this study. Specifically, this related to aggregated estimates for the 56 sub-catchments used in the E2 Catchment Model across the three broad areas, loosely based on the zones employed in the ACWS. These comprised the Northern (ACWS Zone 1, 6 catchments covering 156,160 ha), Central (ACWS Zone 2, 39 catchments covering 59,483 ha[1]) and Southern (ACWS Zones 3 & 3a, 11 catchments covering 53,301 ha; Figure 9).

Population increase and related numbers of dwellings within each of the catchment areas were derived from current Planning SA high projections from 2006/7-2030/1. However, in order to translate population increases into land use changes, a number of assumptions were required. It is important to note that the use of these projections as a means of parameterising the model should not be construed to mean that the projections have any endorsement by Planning SA or that they reflect the changes that will occur over this period. Much of what Planning SA undertakes in this area is strictly confidential and the information used in the context of this investigation has been used with their advice but *not* their endorsement.

No demographic surveys were performed during this work, and all of the assumptions explicit in the ABS and Planning SA documentation considered in this report are subject to change. The predictions contained in this report therefore simply represent a hypothetical illustration of how any such changes may impact on coastal water quality and do not represent our expectations of planning or population change outcomes.

The assumptions and factors built into the population/dwelling number data include;

- The starting point for the projection is 2006/7.
- There is no change to immigration levels over the projection period.
- There is no significant change in economic climate over the projection period that might affect population growth.
- The projection retains a ten year buffer on land supply relative to population, meaning that there is ten years worth of land available ahead of the projected population level. This requirement has important implications for the availability of land under the High population scenario where the projected dwelling needs are somewhat in excess of land supply at 2030 (otherwise referred to as overflow).

[1] Note that the Central metropolitan Adelaide zone incorporates a large number of stormwater sub-catchment areas that are relatively more fragmented than either the Northern or Southern Zones.

- Land supply occurs in two basic forms – Greenfield (newly allocated non-urban land) and Redevelopment (densification of current urban areas).

There are also a number of factors and assumptions used to translate the population, dwelling and land supply data into the model, including;

- Land usage for each scenario will occur firstly in terms of Greenfield developments rather than redevelopments. This assumption enforces a maximum change on land usage (Greenfield to urbanised) under each scenario and therefore offers a "worst case" change within the constraints of the model.
- Overflow population has been allocated across the three catchments areas in the ratio of 50%:30%:20% for Northern, Central and Southern catchments respectively. This assumption is likely to enforce an overestimate of land use change as some of this overflow would likely spill into areas outside the current catchment areas. As with the use of Greenfield uptake relative to Redevelopment, this approach enforces a similar "worst case" framework on the model.
- Dwelling overflow has been allocated in the same ratio that Greenfield: Redevelopment occurs within each catchment.
- Greenfield developments operate at 10 houses per hectare, while Redevelopment occurs at 20 houses per hectare. This assumption is required to translate dwelling increases into areas of land use change. However these factors are actually points along an uneven gradient of urban housing densities that relate to a number of factors depending on the location (land availability, cost, relationship to CBD, transport, etc.). To attempt to build this into the model was considered too complex, particularly in light of other limitations. Furthermore, the values of 10 houses per hectare for Greenfield developments is well outside the existing values which range from 3.4 in the Southern Adelaide region to 9.4 in the Central Adelaide region.

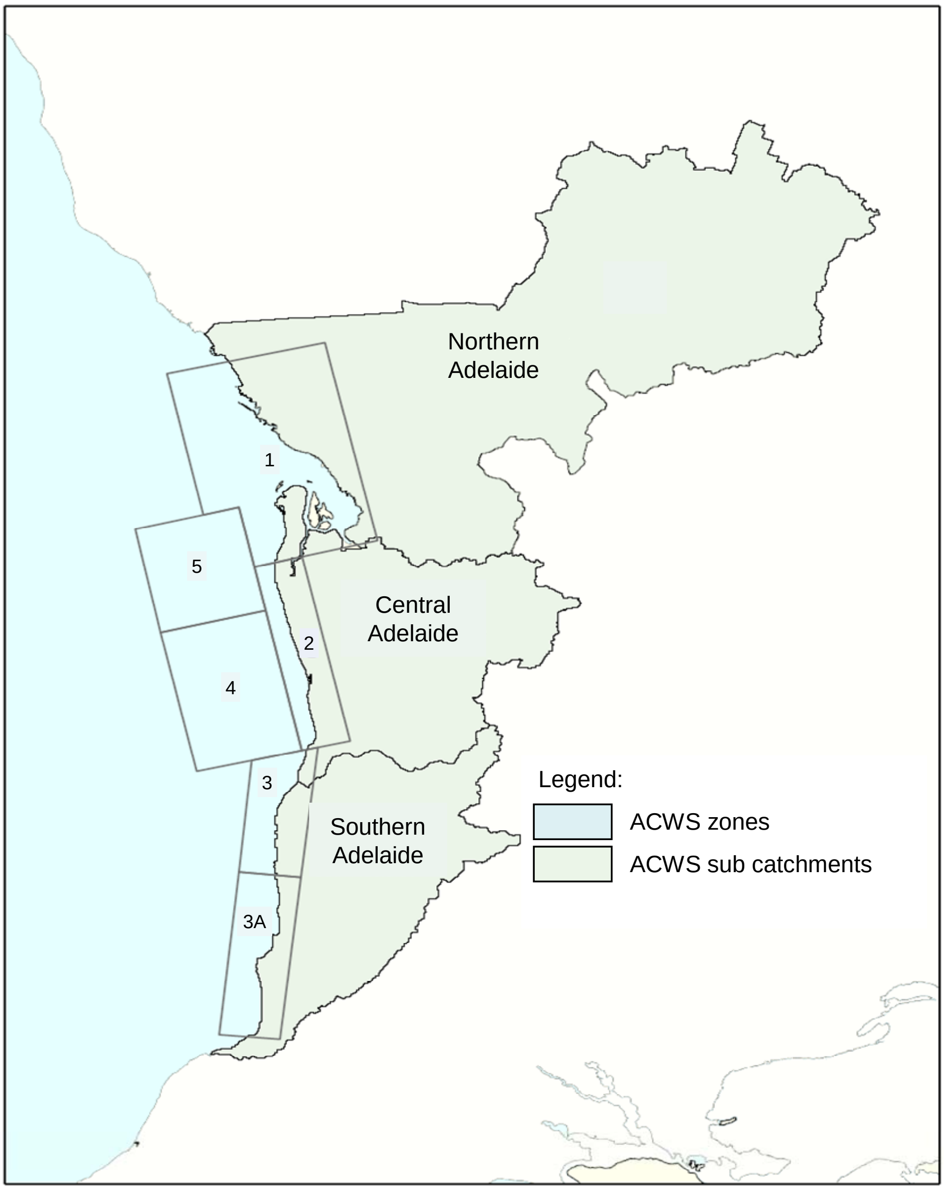

Figure 9 - Greater Adelaide region used for consideration of population growth and changes to catchment impounded areas. The zones used for determining the distribution of population by 2030 closely relate to the Adelaide Coastal Waters Study Zones.

Land use classes are shown in Table 2; this table provides the classification used by Planning SA (Planning SA Land Class), the Functional Unit classification used in E2 Models and an aggregated Land Class that has been used in the ACWS E2 model (as developed by WBM; Weber 2008).

Table 2 – Relationship between Planning SA Land Classes (column 1), the functional units generally employed within the E2 model (column 2) and the aggregated land class units used in ACWS implementation of the E2 model (column 3).

Planning SA Land Class	Generalised E2 Functional	Aggregated Land Class used

	Unit	in ACWS E2 model
Commercial	Commercial/High Density	Dense urban
Education	Commercial/High Density	Dense urban
Public Institution	Commercial/High Density	Dense urban
Retail/Commercial	Commercial/High Density	Dense urban
Forestry	Forestry	Forestry/Openspace
Agriculture	Horticulture/Ag	Hort/Ag
Horticulture	Horticulture/Ag	Hort/Ag
Food Industry	Industrial	Industrial
Utility Industry	Industrial	Industrial
Livestock	Livestock	Grazing
Mine/Quarry	Mining	Industrial
Roads or not specified	Roads	Industrial
Rural Residential	Rural Res	Urban
Golf	Unspecified_OpenSpace	Forestry/Openspace
Recreation	Unspecified_OpenSpace	Forestry/Openspace
Unspecified	Unspecified_OpenSpace	Forestry/Openspace
Vacant Land	Unspecified_OpenSpace	Vacant Land
Non-private Residential	Urban	Urban
Residential	Urban	Urban
Vacant Residential	Urban	Vacant Urban
Waterbodies	Water	Water
Wetlands	Wetlands	Water

5.1 Population / land use change scenarios for SA

Based on the assumptions and available data, the projected number of dwellings required by 2030 within each catchment area under the high population increase scenario was established (Table 3).

Table 3 – Increase in dwelling requirements for medium and high population growth within each of the three catchment areas. Note that the high projection includes the overflow. (Data: Planning SA)

Catchment area	Dwelling numbers (#)		
	Base (2006/7)	Additional required by 2030	2030 Totals
North	129,669	71,164	200,833
Central	311,450	66,064	377,514
South	64,027	30,087	94,114

Based on the land supply data, increases in the number of dwellings within North, Central and Southern areas can be translated to areas of land use change (Table 4).

Table 4 – Areas of land use change within each catchment area by 2030 under high population growth projection. (Data: Planning SA).

Catchment area	Greenfield (ha)	Redevelopment (ha)	Greenfield (# new dwellings)	Redevelopment (# new dwellings)
North	5423	846	54,230	16,920
Central	2587	2010	25,870	40,200
South	2380	314	23,800	6,280

Estimates of the current land class allocations (Table 5) can then be combined with the projected change in population numbers and land use change (Table 3, Table 4) to provide an estimate of the 2030 land class allocations (Table 6) using the assumptions about allocation and land supply detailed above.

Table 5 - Current (2006/2007) dwelling numbers and land use allocations in area (ha) between the 3 regions broken down by land use functional classification. The dwelling density factor is a measure of the number of dwellings per ha in Urban areas on the assumption that Dense Urban areas have double the density shown. Dwelling numbers in each land class have then been calculated by allocating dwellings to urban vs dense urban Land Classes based on the current areas (ha) of these land classes in each region and the total number of dwellings.

	Nthn Adelaide	Central Adelaide	Sthn Adelaide
Dwelling density factor	3.6	9.4	3.4
		Dwelling number by region	
Urban	126,820	235,400	58,440
Dense Urban	30,084	76,050	5,587
Total number of dwellings	156,905	311,450	64,027
Land classes		**(ha) by region**	
Water	976	456	504
Grazing	22,864	1,771	8,415
Hort/Ag	56,702	2,543	12,813
Forestry/Openspace	5,686	7,436	5,010
Vacant Land	3,731	2,909	1,885
Vacant Urban	1,563	2,098	1,016
Urban	35,228	25,118	16,999
Dense urban	4,178	4,057	813
Industrial	25,232	13,094	5,845
Grand Total (ha)	**156,160**	**59,483**	**53,301**

Table 6 – Estimated dwelling numbers and land use allocations for 2030 between the 3 regions broken down by land use functional classification. The dwelling density factor is a measure of the number of dwellings per ha in Urban areas on the assumption that Dense Urban areas have double the density shown. Dwelling numbers in each land class have then been calculated by allocating dwellings to urban vs dense urban Land Classes based on the current areas (ha) of these land classes in each region and the total number of dwellings.

	Nthn Adelaide	Central Adelaide	Sthn Adelaide
Dwelling density factor	4.0	9.5	4.4
		Dwelling number by region	
Urban dwellings	161,028	262,527	84,311
Dense Urban dwellings	39,805	114,987	9,803
Total number of dwellings	200,833	377,514	94,114
Land classes		**(ha) by region**	
Water	976	456	504
Grazing	21,444	1,016	7,484
Hort/Ag	53,181	1,460	11,396
Forestry/Openspace	5,333	4,267	4,456
Vacant Land	3,731	2,909	1,885
Vacant Urban	1,563	2,098	1,016
Urban	39,961	26,257	16,999
Dense urban	4,740	7,926	3,714
Industrial	25,232	13,094	5,845
Grand Total (ha)	**156,160**	**59,483**	**53,301**

The changes required to accommodate these new dwellings are in the allocation of Vacant, Vacant Urban, Urban and Dense Urban land as summarised in Table 7.

Table 7 – Changes in land allocation difference in area by region between Table 5 and Table 6.

Land classes	Nthn Adelaide	Central Adelaide (ha) by region	Sthn Adelaide
Water	-	-	-
Grazing	-1,420	-755	-931
Hort/Ag	-3,521	-1,084	-1,417
Forestry/Openspace	-353	-3,169	-554
Vacant Land	-	-	-
Vacant Urban	-	-	-
Urban	4,733	1,139	-
Dense urban	561	3,868	2,901
Industrial	-	-	-

6 Modelling stormwater inputs to the Adelaide metropolitan coast

The original intention of this study was to assess the impact of Climate and Population change (as detailed in Sections 4 and 5 above) on stormwater input and coastal water quality for the Adelaide region by using the ACWS E2 Catchment Model (as per Weber 2008).

After preliminary work, examples of which are presented in the following, it was concluded that the ACWS E2 Catchment Model could not be used to test the effect of these climate and population change scenarios in part because the Weber (2008) implementation of the model does not capture the complexity of a number of key processes that impact on stormwater quality and particularly the contaminant generation processes (details of these limitations are provided in Section 7 below). However, there are also issues related to lack of spatial and temporal resolution of the input data in terms of both climate and population, in particular the way in which this implementation of the model only considers the three broad catchment groups (North, Central and South) and the lack of spatial resolution on climate data.

In the following we provide examples of the key outputs from the current implementation of the model with a view to highlighting the problems that one would need to address before this implementation of the model can be used for the purposes of a study such as that originally envisaged in the definition of the current project.

6.1 The effect of climate change on stormwater volumes

The climate change scenarios defined in Table 1 (Section 4.6) were used in the model to predict the effects of changed temperature, rainfall and evapo-transpiration on Adelaide Coastal Water quality (Figure 10).

Using these scenarios the model predicts that stormwater discharge will reduce by up to 50% relative to the current rainfall patterns (10^{th} Percentile Scenario), the "best estimate" (50^{th} Percentile Scenario) provides for a 20% reduction in stormwater flows while the other extreme (90^{th} Percentile Scenario) provides for a small (up to 10%) increase in the volume of stormwater discharged relative to the current climate (Figure 10).

Taken in isolation these predictions may seem reasonable but it needs to be recognized that these estimates are based on a number of critical assumptions including that the physical properties of the landscape that drive runoff and base flow are unchanged and that the only determinant of runoff volumes is rainfall volume and timing.

It can be argued that under any climate change scenario leading to substantial reductions in rainfall (i.e. both the 10^{th} and 50^{th} Percentile Scenarios) there will be concomitant changes in landscapes including compaction of soils and changes in vegetation structure (affecting standing biomass, root structure and penetration and even species mix). These changes are likely to have a profound impact on the relationship between rainfall volumes and runoff rates and these changes can not be accounted for in this implementation of the model.

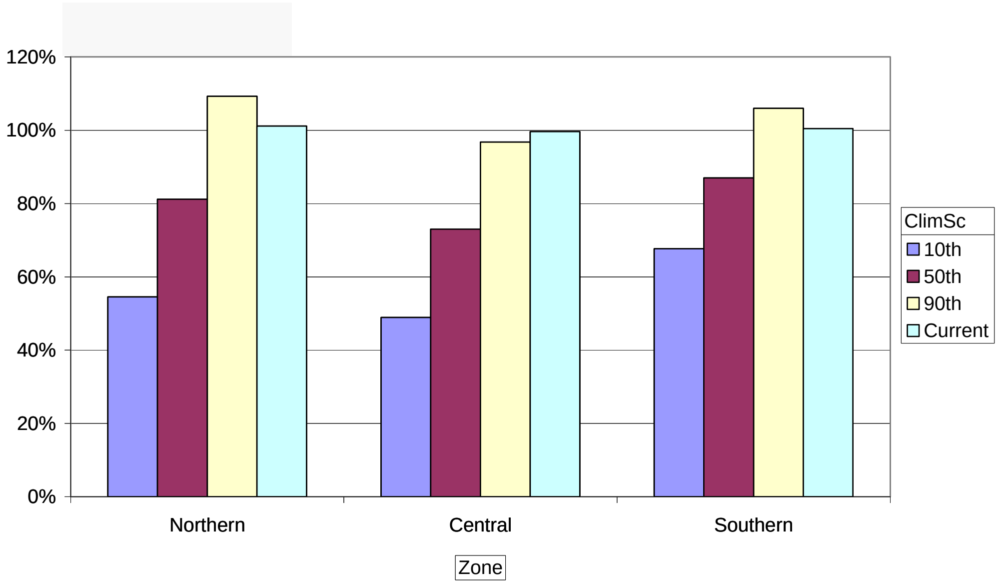

Figure 10 - Comparison of the ACWS E2 model predictions for stormwater discharge rates under 3 different climate change scenarios (10th, 50th and 90th Percentile Scenarios; see Table 1) and the Current rates of stormwater discharge (final bar in each group). The 10th and 50th Percentile Scenarios result in a reduction in discharge rates (by up to 50%). The 90th percentile suggests that discharge rates will remain similar (or even slightly exceed) those under current climate conditions.

6.2 The effect of climate change on stormwater quality (contaminant loads)

In addition to estimating changes in stormwater volumes the ACWS E2 model has been used to predict changes in stormwater quality. Stormwater quality is predicted by combining model predictions on stormwater volumes with estimates of the contaminant generation rates which are defined via the values assigned to the EMC (Event Mean Concentration) and DWC (Dry Weather Concentration) parameters, which in turn vary by land class (Table 8).

Table 8 - Values used by the EPA to parameterise EMC and DWC values for the various land use classes.

	Event Mean Concentrations (mg/L)				Dry Weather Concentrations (mg/L)			
Land Class	TOC	TP	TN	TSS	TOC	TP	TN	TSS
Agriculture/Horticulture	25	0.36	2.1	140	8.3	0.07	0.7	10
Dense urban	30	0.28	1.6	140	13.1	0.07	0.7	10
Forest/Open space	9.5	0.2	0.8	20	4.8	0.03	0.4	7
Grazing	19	0.28	1.6	140	8.3	0.07	0.7	10
Urban	19	0.28	1.6	140	8.3	0.07	0.7	10
Water	0	0	0	0	0	0	0	0

It is important to note that the current ACWS implementation of the E2 model makes the assumption that the EMC and DWC values remain the same, for any given land use class, under all climate change scenarios. In essence this assumption means that any change in rainfall pattern will impact on stormwater quality in direct proportion to the changes in stormwater volume and that no account will be made for climate change effects on land condition in the catchment.

In simple terms, this assumption means that a 50% reduction in stormwater volumes (as expected under the 10th Percentile Scenario) will necessarily result in a 50% reduction in contaminant discharges to the coastal waters. This is illustrated graphically in Figure 11 which shows the expected changes in total nitrogen discharge (TN) plotted against stormwater volume changes under the various climate and population change scenarios.

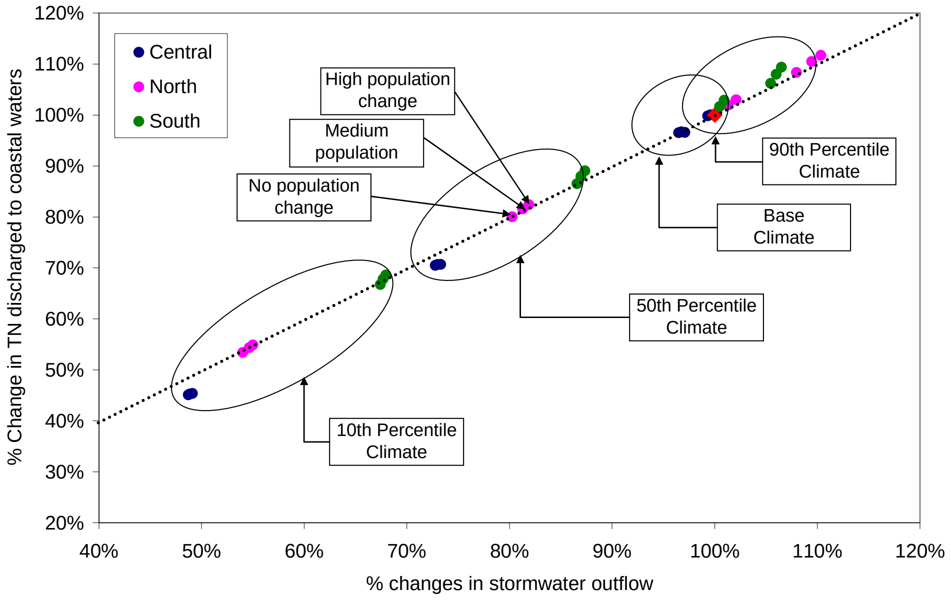

Figure 11 –Modelled changes in Total Nitrogen (TN) discharge loads under the various climate and population change scenarios. Note the dotted line showing the linear relationship between percent change in stormwater volumes (x-axis) and % change in TN (y-axis).

The assumption that EMC and DWC values are invariant in relation to changes in rainfall patterns is not likely to be valid. There are numerous reasons to question this assumption including:

1. If climate change results in less frequent rain events it is reasonable to expect that there will be a greater build up of mobile contaminants across the catchment during the intervening periods. When rainfall events do then occur it is probable that they will mobilize larger quantities of contaminants (i.e. the EMC values are likely to be elevated).
2. Rainfall events are also likely to become more intense (short, energetic, big events rather then persistent, less volatile, small events). This will change the mobility of many contaminants and give rise to further changes in the EMC values).
3. Changes in the structure of the catchment (vegetation and soil condition) will change the mobility of contaminants in both dry and wet conditions and give rise to changes in both EMC and DWC values.

On this basis it does not seem reasonable to assume that contaminant loads to coastal waters will vary simply and on a linear basis with rainfall volumes. The modelled pattern of change shown in Figure 10 is therefore likely to be unrealistic and grossly miss-representative of the expected changes in the quality of waste water discharged into coastal systems.

6.3 Impact of population change on stormwater quality

The population change scenarios detailed in Section 5.1 have been incorporated into the model through changes in the land use allocation (functional units). The predicted changes in storm water quality are all very marginal (Figure 12) because the only estimates provided in relation to population change relate to the area allocated to housing across the three summary zones (North, Central and South).

In reality, population changes will not only impact on land supply for housing but also on the area of land allocated for employment related purposes. This would result in changes to the areas allocated for industrial and commercial use as well as areas allocated for community services (hospitals, schools, transport corridors, etc.).

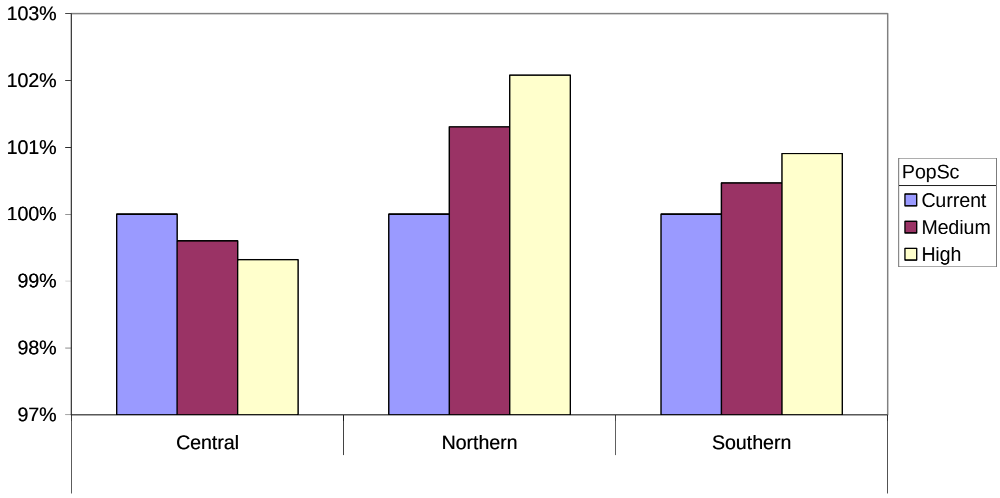

Figure 12 - Percent changes in stormwater volumes under current climate conditions for three population change scenarios. Current – 2006/07 population, Medium Growth and High Growth scenarios (as detailed in Table 3, Section 5.1). Limitations in the ACWS implementation of the E2 model mean that associated changes in stormwater volumes relate only to changes in land use for housing and do not reflect concomitant changes in the allocation of lands for community, commercial or industrial purposes across the three catchments.

6.4 Summary

The ACWS E2 model can provide highly resolved information on the nature of stormwater generation at the catchment/sub-catchment level. However, the current implementation of the ACWS E2 model is unable to account for many of the changes in catchment condition and land use that would reasonably be expected as a result of climate and/or population change.

In broad terms this relates to the fact that key model parameters including EMC, DWC, Land Class and Rainfall Runoff are not linked to the driving variables of population and climate. If the model is to be used in this broader context then there needs to be a much more explicit process for relating the values allocated to these parameters to the population and climate change scenarios that are being evaluated. This requirement is illustrated schematically in Figure 13 with the inclusion of specific relationships between the driving variables and the model control parameters (see magenta lines in Figure 13).

While this figure presents a schematic view of the changes needed these are documented in more detail in the following (Section 7).

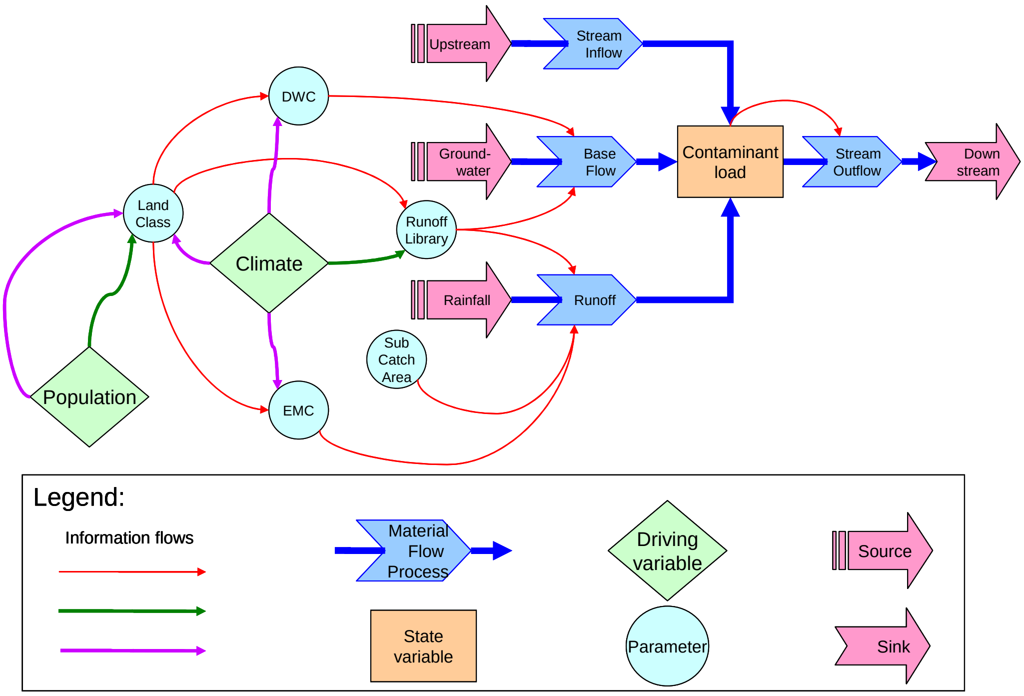

Figure 13 – Revised schema showing a more ideal representation whereby Climate and Population Change are linked to a broader range (magenta arrows) of E2 model parameters and thereby will better reflect the relationship between changed land use and condition on contaminant generation and ultimately on coastal water quality.

7 Issues related to the current ACWS E2 model for the purposes of population and climate change prediction

As it currently stands, the ACWS E2 model can provide useful predictions on the relationship between land use, stormwater runoff and contaminant loads at the catchment/sub-catchment level. However, for the purposes of predicting the effect of global climate and/or population change scenarios the current implementation of the ACWS E2 model has limited utility.

Broadly, the limitations relate to the nature and scale of the questions that can be addressed and this can be related directly to the availability of data with which to parameterise the model for this application.. The need to consider population data across three very large catchment areas has substantially impacted on the utility of the resulting predictions. Furthermore, the input climate scenarios were necessarily based on historical data which fails to encompass some of the key aspects of global climate change for southern Australia, in particular, that extreme weather events are likely to be less predictable and more energetic under most scenarios.

The current ACWS E2 model therefore has a number of critical limitations in terms of its application to this project including:

1. The current values for EMC and DWC across different land uses (Functional Units) are of questionable utility due to the paucity of event based water sample collection and calibration data across catchments. Lack of calibration data means that we can have little confidence in the extent to which changes in land use can be translated into meaningful estimates of stormwater contaminant loads, even under current conditions.
2. Many of the likely climate related changes in catchment use and condition cannot be incorporated into the model due to a lack of information on the relationship between EMC, DWC and the relevant climatic forcing.
3. The impact of land use changes associated with urban development and urban in-fill are not well defined spatially across catchments or in relation to the EMC and DWC values. This limits our capacity to predict changes in coastal water quality associated with population change.

Each of these issues is dealt with in more detail below.

7.1.1 Quantification of EMC and DWC values across land use functional units

Values for EMC and DWC are poorly defined for the region. This relates to a number of issues which are not fully resolved in the current implementation of the model. In summary:

1. While the current implementation provides some indication of the effect of differences in land use on both EMC and DWC values (see Table 8) these are poorly resolved due to the limited amount of data collected through storm event monitoring. Necessarily, EMC and DWC values are assumed to be constant, for any given land class, across the entire region, even though any number of examples exist for differences in stormwater management across different landscapes within the region. Examples include the development of stormwater management systems including the aquifer storage and recovery programs at Salisbury and the Grange Golf Club. These developments are evidence that we have land uses across the catchments that will generate different contaminant loads even though they may be classified within the same land use class. This problem is exacerbated when one considers the issues detailed in 2 below.

2. Land condition (soil and vegetation) and physical properties (slope and aspect) vary across the catchment and there is also variability in climate, historical land use and current land management practices (e.g. grazing vs cropping vs horticulture etc). These differences mean that EMC and DWC values are not likely to be constant for any given land class either between or within catchments. While land use classes are a potentially useful classification types for broad scale mapping, they tend to lack the capacity to offer an appropriate level of detail in actual condition to allow predictive capability because of the large number of variable factors that will differ even within a land use type. In effect, contaminant generation rates are likely to vary irrespective of land class and the use of a single set of EMC and DWC values for a single land use type are unlikely to be representative of the actual values for any given land area.
   Further work is required to better quantify the variability in contaminant generation rates within the various land use classes across the catchment.

3. Many of the EMC and DWC values that have been assigned to various land use classes are inappropriate. While the purpose of this study was not to provide absolute values for each of these land uses we can make a reasonable argument that the relativities are likely to be poorly estimated. For example, the ACWS implementation of the E2 model makes the assumption that contaminant loads from mining sites are the same as those from commercial sites which include schools and shopping centres. Given the fundamental differences in sediment mobilisation processes between these land uses it seems unreasonable to class them as equivalent in terms of contaminant generation rates.
   Further work is required to better resolve the contaminant generation rates by land use class for the entire region.

7.1.2 Climate change effects on catchment use and condition

The current implementation of the ACWS E2 model is only able to resolve changes in rainfall patterns (timing and volumes) and evaporation rates associated with climate change. While these are clearly important effects of climate change, there are many other likely impacts, some of which will probably have a profound impact on stormwater discharge quality and contaminant loads. In summary the following issues remain to be resolved with regard to climate related impacts on stormwater contaminant loads:

4. Changes in stormwater management and reuse policy are already occurring in response to climate change and the concomitant need for improved water security. Significantly, activities such as stormwater harvest and re-use will have profound implications for the volume of stormwater discharges (e.g. diversions to ASR or similar re-use technologies). Coupled with this there is likely to be more development of "in-stream" treatment systems (e.g. current plans to incorporate sedimentation basins along Christies Creek). These changes will reduce discharge volumes and contaminant concentrations with concomitant reductions to discharge loads to coastal waters. The current model does not make provision for changes in catchment linkages or for the introduction of discharge and quality management strategies both of which have implications for contaminant loads.

5. Changed land use as a result of climate change is an adaptation strategy that will allow primary producers to respond to the physical impacts of climate change. Such changes in land use may include, for example, switching from cropping to grazing, changing crop types or changing farming practices (e.g. adoption of conservation farming) all of which are likely to occur as farmers attempt to make better use of their land and water resources and will undoubtedly result in changes to both the EMC and DWC values for different land classes. The extent to which this occurs is also likely to vary across

the catchments depending on local conditions and management arrangements. The current model does not adequately resolve such differences and hence no estimates of the effects on coastal water quality can be made. Land management practices in conservation/forestry areas are also likely to change.

6. Climate change is also likely to result in changes to landscapes associated with increases in key climate variables such as temperature and evapo-transpiration. Substantial changes in vegetation and soil quality are likely to occur as a result, giving rise to concomitant changes in EMC and DWC values. The extent to which this occurs is likely to be variable across the catchment depending on both current land use and condition as well as on physical conditions such as slope, aspect and geomorphology. No provision is made in the ACWS E2 model for changes in contaminant loads associated with climate forced changes in land condition.

7. Many changes are likely to occur in coastal waters which include warming and possibly greater differences between summer and winter temperature extremes. In addition, there is potential for changes in salinity and pH which may also influence coastal hydrodynamics and mixing due to modifications to density driven thermohaline circulation in Gulf St Vincent. Modifications to wind driven mixing and exchange processes may also occur associated with overall climate condition.

   The effects of these changes on the existing benthic communities within the Gulf (in particular seagrass systems) are not understood at this time. Collectively these factors have the potential to profoundly influence the physiology, ecology and physical processes in coastal waters and therefore how they respond to changes in contaminant loads from land based discharges. It is not possible, in the absence of substantial additional research, to make any meaningful predictions about whether these changes will have a positive or negative impact on coastal water quality.

7.1.3 Effect of population change on contaminant generation

Population increase will result in a change in land use. This will be most apparent in the expansion of the amount of urban land under development and densification of existing urban land through in-fill and redevelopment. These changes involve the reallocation of existing land classes to these alternative uses. While we have some data on the expected changes in land use associated with urban development there are still substantial limitations to these data including:

8. Data on changes in the area of lands allocated to urban and dense urban development are not well defined in a spatial context across the catchments because the data (as supplied by Planning SA) for the project were highly aggregated into three zones (northern, central and southern). It is probable that limitations in land supply will result in a variety of reallocations that are not consistent with the current expectations or the assumptions being used by Planning SA. The model needs more highly resolved data on expected changes in land use (e.g. broken down across sub-catchments) so that these can be correlated with land supply and thereby used to provide better estimates of land use change. However, it needs to be acknowledged that much of the future planning for urban developments and related infrastructure is highly confidential due to the market liabilities and context. Notwithstanding this issue, the degree of spatiotemporal resolution on population scenarios with reference to catchments/sub-catchments could be more fully explored.

9. There is a need to provide additional estimates for the likely changes in the allocation of land to commercial, social and/or industrial uses which will be required to support the expected changes in population (e.g. new industrial or commercial developments

will be required to provide employment as population grows). The need for these developments will also require changes in land use and the model needs to make provision for these changes which will be additional to those associated with urban residential development (as in 8 above). Similarly, there will be a need to define this type of land use change across the sub-catchments and to correlate the requirements to existing land supply (although note the caveat in 8 above). This will then provide much better estimates of the total land use changes and thereby allow a more robust estimate of the impact on contaminant generation rates.

10. The model makes very coarse estimates of changes in both EMC and DWC for urban and dense urban areas and assumes that these are the same irrespective of the area in which they occur or the actual density of housing. Estimates of contaminant generation need to be revised to better reflect the nature of these (re)developments including those that employ water sensitive design principles incorporating improved (e.g. on-site) stormwater management or re-use.

In summary the current implementation of the ACWS E2 model is not an effective tool for investigating population and climate change scenarios, in large part because of the limitations of the available input data, but also due to a range of issues within the model itself. The ACWS implementation of the model is poorly calibrated, makes very coarse estimates of both EMC and DWC contaminant generation, assumes that these values are constant across the entire catchment and thereby makes little provision for changes in land use or catchment condition. However, results of this study have clearly highlighted the requirements for moving forward, with substantial work required in order to:

1. Provide spatially and functionally resolved estimates of contaminant generation;
2. Better define how climate will impact on contaminant generation through changes in land use, land condition, rainfall pattern and the likely influence of stormwater management;
3. Better define the land use changes associated with urban (re)development, industry and commercial development and the problems with indeterminate strategies for managing land supply; and
4. Develop an improved input climate dataset that incorporates predictions with respect to temperature, humidity and rainfall changes, but also brings more in terms of an increased number of more extreme weather events.

8 References

ABS (2006). *Population projections Australia. 2004 to 2101 Reissue.* Catalogue number 3222.0

ABS (2008). *Regional population growth, Australia 2006-2007.* Catalogue number 3218.0

AMLR NRM (2008). *Creating a sustainable future: An integrated natural resources management plan for the Adelaide and Mt Lofty Ranges region. Volume B – Ten year plan for the region.* Adelaide and Mt Lofty Ranges Natural Resource Management Board, Adelaide.

Cameron J. (2003). *Near shore seagrass change between 1995/6 and 2002 mapped using digital aerial orthophotography. Metropolitan Adelaide area: North Haven – Sellicks Beach, South Australia.* A report for the Environmental Protection Authority, Department of Environment and Heritage, South Australia. Image Data Section, Environmental Information Directorate, Department of Environment and Heritage, South Australia.

CSIRO 2007. *Technical Report 2007: Climate Change in Australia.* ISBN 9781921232947

EPA (1998). *Changes in seagrass coverage.* Adelaide, Environment Protection Agency (SA)**.**

EPA (2008). *Adelaide Coastal Water Quality Improvement Plan – Draft.* South Australian Environment Protection Authority.

EWS (1975). G*ulf St Vincent water pollution studies 1972 – 1975.* EWS 75/14. Engineering and Water Supply Department, Adelaide, South Australia.

Fox, D.R. (2006). *Adelaide coastal waters study.* Draft final report prepared for the South Australian Environment Protection Authority.

Fox, D.R., Batley, G.E., Blackburn, D., Bone, Y., Bryars, S., Cheshire, A., Collings, G., Ellis, D., Fairweather, P., Fallowfield, H., Harris, G., Henderson, B., Kämpf, J., Nayar, S., Pattiaratchi, C., Petrusevics, P., Townsend, M., Westphalen, G. and Wilkinson, J. (2007). *The Adelaide Coastal Water Study Final Report, Volume 1.* Prepared for the South Australian Environment Protection Authority. CSIRO Marine and Atmospheric Research.

Garnaut, R. (2008). *The Garnaut Climate Change Review: Final Report.* Cambridge University Press (Melbourne). Pp 634

Government of South Australia (2005). *Waterproofing Adelaide: A thirst for change.* Government of South Australia and Watercare Australia – Salinity and Water.

Government of South Australia (2007). *South Australia's Strategic Plan 2007.* Government of South Australia.

Hart D.G.D. (1997). *Near-shore seagrass change between 1949 and 1996 mapped using digital aerial orthophotography. Metropolitan Adelaide area: Largs Bay – Aldinga, South Australia.* A report for the Environmental Protection Authority, Department of Environment and Natural Resources, South Australia and SA Water. Image Data Services, Resource Information Group, Department of Environment and Natural Resources, South Australia.

Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) (2006). *Impacts of climate change on Australian marine life: Part A. Executive Summary.* Report to the Australian Greenhouse Office, Canberra, Australia.

IPCC (2007). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. In Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Shepherd S.A. (1970). *Preliminary report upon degradation of seagrass beds at North Glenelg.* Unpublished report, South Australian Department of Fisheries, p. 29.

Shepherd S.A., McComb A.J., Bulthuis D.A., Neverauskas V.P., Steffensen D.A. and West R. (1989). Decline of seagrasses. *In*: Larkum A.W.D., McComb A.J. and Shepherd S.A. Eds. *Biology of seagrasses.* Elsevier, Amsterdam, pp. 346-388.

Steffensen D.A., Kirkegaard I. and Johnson J. (1989). *Position and background papers on man-made changes to Gulf St. Vincent. Adelaide.* South Australian Committee on Pollution of Gulf St Vincent. Government of South Australia, Adelaide, p. 27.

Timbal, B., Murphy, B., Braganza K., Hendon, H., Wheeler M., Rakich, C., 2007. *Compare documented climate changes with those attributable to specific causes*. Final Report for Project 1.1.2 of the South Eastern Climate Initiative. Bureau of Meteorology.

Turner, D. J., Kildea, T. and Westphalen, G. 2007. *Examining the health of subtidal reef environments in South Australia, Part 2: Status of selected South Australian reefs based on the results of surveys undertaken in 2005.* SARDI Aquatic Science. SARDI Publication Number RD03/0252-6: 81.

Weber, T. (2008). *Modelling the catchments of the Adelaide coastal waters.* Draft report to the Environment Protection Authority. BMT WBM Pty Ltd.

Westphalen, G., Collings, G., Wear, R., Fernandes, M., Bryars, S. and Cheshire, A. (2004) "*A review of seagrass loss on the Adelaide metropolitan coastline*". ACWS Technical Report No. 2 prepared for the Adelaide Coastal Waters Study Steering Committee. South Australian Research and Development Institute (Aquatic Sciences) Publication No. RD04/0073, Adelaide.