1 Climate Change

Overwhelming scientific evidence suggests that the climate within the Avon River basin (ARB) is changing, and will continue to change, most likely for generations into the future. It is clear that South West WA has experienced a decline in rainfall since the 1970s, and these trends in declining rainfall are generally consistent with modelled scenarios for climate change for the region (CoA 2007).

The most recent research has found that weather patterns in South West WA include (IOCI 2012):

- *A drying trend for the period May–July over the last 10 years*
- *Early winter rainfall increasingly driven by high pressure systems as opposed to deep lows, which was formally the case*
- *Autumn rainfall has declined by 15% since 2000, principally due to increasing prevalence of high pressure systems*
- *Increased frequency of tropical cyclones in the North*
- *Increased drought conditions.*

These findings are of particular significance because they link changing rainfall patterns to a fundamental change in climatic patterns. A reduction in winter storm intensity and atmospheric instability over South West WA is associated with a reduction in the velocity of the subtropical jetstream in addition to thermal changes in the structure of the atmosphere. Essentially, there is less energy in our atmospheric systems which means more stable atmosphere resulting in less intense winter storms (IOCI 2012).

The signal of rainfall decline in South West WA is considered exceedingly robust. The most recent climate modelling strongly suggests that large-scale atmospheric changes associated with South West WA rainfall reductions are consistent with those expected from atmospheric impacts associated with increased greenhouse gas concentrations (IOCI 2012).

Climate models describing the current reduction in rainfall being experienced in South West WA also predict a further decline in rainfall. Future climate patterns for South West WA are likely to include (IOCI 2012):

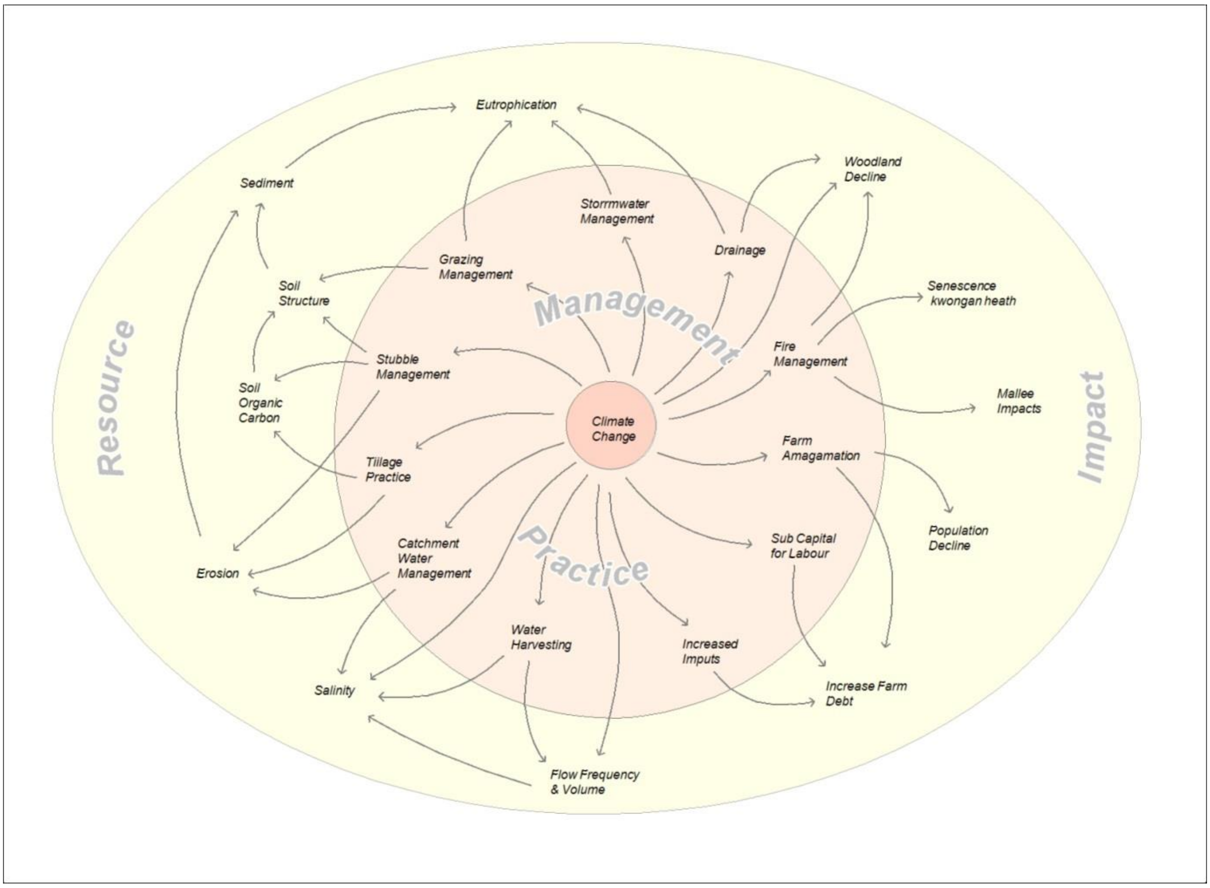
- *Reduced rainfall from May to October inclusive*
- *High-pressure weather systems becoming more prevalent and low-pressure systems less prevalent*
- *The expansion and intensification of the drying trend through to the end of the 21st century*
- *Increasing frequency and severity of drought conditions*
- *Increases in extreme rainfall events associated with more southerly passage of tropical storms* (note that assessment of extreme events is still considered preliminary)
- *Increased temperatures, and increased temperature extremes* (IOCI 2012).

Our changing climate will result in a range of environmental and socio-economic consequences, including impacts on agriculture and water resources and loss of biodiversity and associated environmental impacts. Understanding the probable nature of climate change at a regional scale is critical, yet the likely impact of these changes on local communities, economics and industry and infrastructure are generally not well understood (CoA 2007).

1.1 Background

Climate change is central to many of the NRM processes that occur throughout the region, impacting resource condition both directly and through a myriad of land management practices (refer Figure 1).

Figure 1. Impacts of Climate Change on Land Management Practice and Resource Condition.



Climate variations are indeed central to many of the systems and functional processes that occur within the region, impacting farm management practice, biodiversity management, and the underlying socioeconomic fabric of the region. As an external stressor, there is no greater force shaping the underlying condition of the region or the capacity of the regional and broader communities' ability to respond to the mounting challenges to NRM facing the region.

Changes to rainfall patterns in our region are predicted to be moderate to severe, with a reduction in rainfall of up to 30% by 2050 when compared to 1990 rainfall (CSIRO & BOM 2007), caused by an up to 70% increase in the incidence of high-pressure systems and a coinciding reduction in incidence of low-pressure systems (IOCI 2012). Whilst there is some uncertainty in the predictions of our future climate, all forecasts predict a drying trend and predictions of trends for our region are considered extremely robust.

Analysis has linked recent reductions in autumn and winter rainfall to changes in the frequency and intensity of low-pressure systems impacting South West WA, caused by fundamental changes to the prevailing atmospheric conditions resulting from increases in greenhouse gas concentrations (IOCI 2012).

Table 1. Predicted Reduction in Precipitation of South West Western Australia Compared with 1990. (Source: CSIRO & BOM, 2007)

2030	2050	2070
0–15%	0–30%	0–40%

Models for the South West predict up to an 80% increase in drought months (low or no rainfall) accompanied by an increase in storm intensity and associated erosion events (CSIRO & BoM 2007).

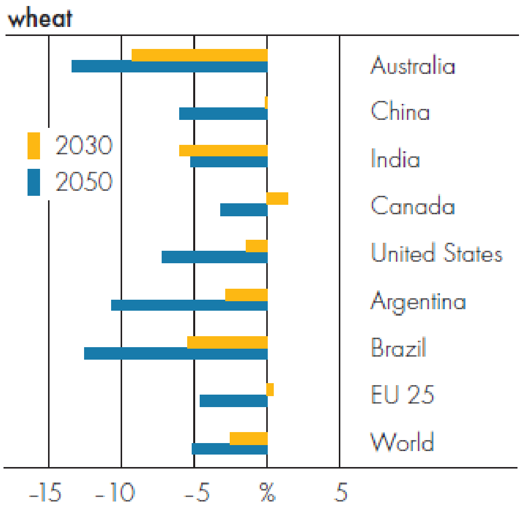
Hotter and drier conditions are also likely to result in increased fire risk and intensity. We are predicted to experience a reduction in the total number of tropical cyclones, but cyclone intensity is predicted to increase in addition to an elevated risk of ex-tropical cyclone depressions impacting the Avon River Basin, resulting in increased frequency of extreme rainfall events (CSIRO & BoM 2007, IOCI 2012).

1.2 Agriculture

Changes in climate will increase strain on the productivity of agriculture within the Avon River basin, particularly as most recent predictions are for a reduction in rainfall throughout the growing season (May–October) (IOCI 2012). The impact of climate change on agricultural production is predicted to be worse in Australia than in other countries, particularly over the next two decades (refer 2).

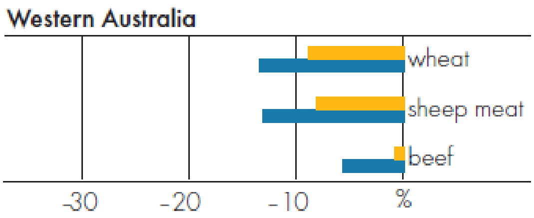
ABARE modelling indicates that Australia will experience a reduction in agricultural production as a result of the effects of climate change, predicting a 13% decline in overall production by 2070 (Gunasekera et. al. 2007).

Figure 2. Changes in Global Wheat Production *(Source: Gunasekera et al. 2007)*



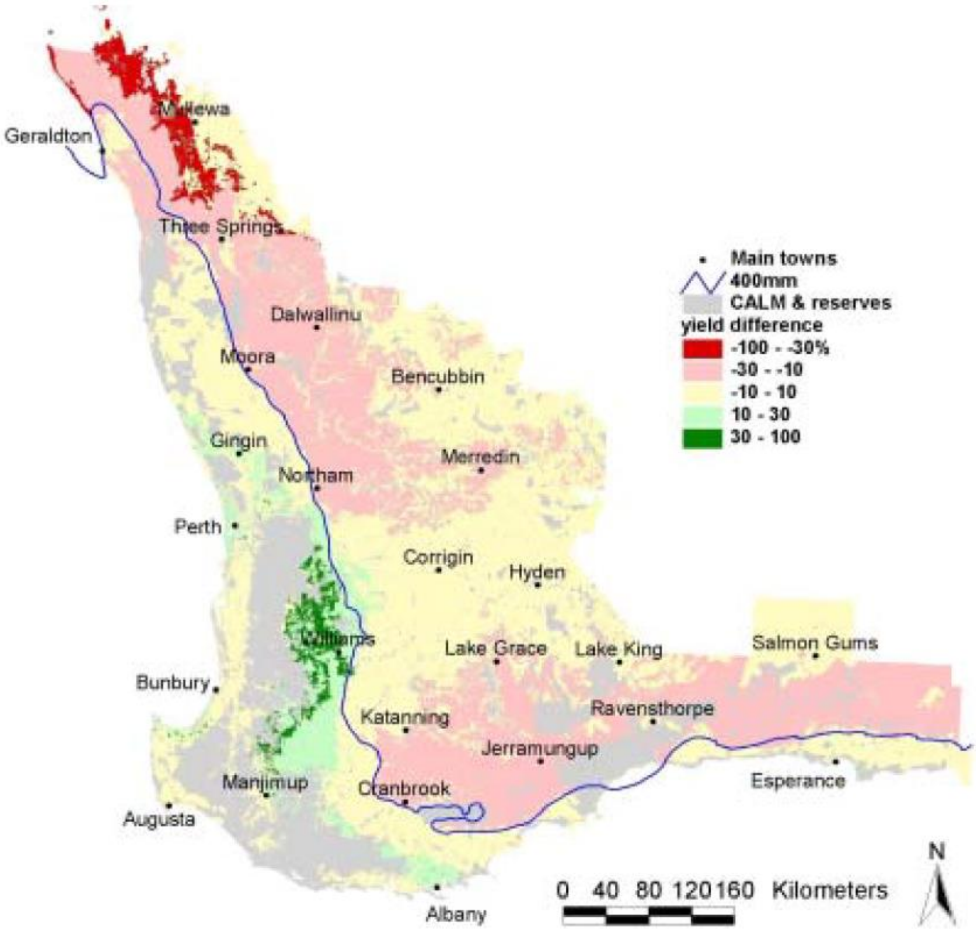
Grain production in Western Australia is predicted to decrease by 9% and 14% by 2030 and 2070 respectively as a result of climate change impacts, placing increasing strain on an industry already struggling to achieve the productivity gains required to maintain profitability in the face of declining terms of trade (Gunasekera et al. 2007).

Figure 3. Predicted Changes to Agricultural Production for Western Australia (*Source: Gunasekera et al. 2007)*



DAFWA undertook modelling of wheat yields using rainfall simulations generated by the OzClim model, a climate change scenario model developed by the CSIRO atmospheric research team. In undertaking yield modelling, DAFWA assumed no significant changes in management practice, stable carbon dioxide (CO_2) concentrations and averaged climate conditions, excluding impacts of extreme rainfall events (van Gool & Vernon 2005).

Figure 4. Predicted Changes in Wheat Yield over a 50-year Scenario, Based on Average Rainfall Reductions Associated with Climate Change Modelling of the South West (Source: van Gool & Vernon 2005)



The modelling undertaken by DAFWA (Figure 4) indicates a reduction in wheat yield potential throughout the majority of the agricultural area of WA over the coming decades. The 30$^+$% yield decline predicted for north of Three Springs is largely due to increased temperatures, with rainfall change having a relatively minor influence. The 10–30% predicted reduction in wheat yields throughout the northern agricultural areas (north of Northam) and south of Lake Grace and Katanning is principally due to a predicted decline in rainfall.

The modelling is considered only a guide, as the impact of high temperature on wheat yields remains a subject of debate, and other modelling undertaken by Howard et al. (1999) indicates that increased CO_2 levels may ultimately lead to increased wheat yields. The modelling considers that moisture is the key limiting factor influencing yield throughout most of the agricultural area, suggesting a moderate reduction in yield over the coming decades.

Whilst there is uncertainty regarding the extent of the impact climate change will have on agricultural production within the region, all reputable forecasts clearly predict a significant drying trend and a corresponding yield reduction.

1.2.1 Trade Impacts

The trade implications of climate changes arise from the interaction of two key factors: a potential reduction in agricultural output from key producing countries, and a slowdown in the global economy brought about by climate-related impacts. These climate-related impacts include market impacts (impacts on the energy sector), non-market impacts (impacts on the environment) and catastrophic impacts (caused by extreme events such as cyclones) (Stern 2006).

Global demand for grains is likely to remain relatively steady because of their importance in basic dietary requirements, but future demand for livestock products is likely to reduce, particularly in developing countries (Gunasekera et. al. 2007).

1.2.2 Adaptation

Adaptation to changing weather patterns will be essential if landholders within the region are to remain profitable into the future. Adaptation to climate change will require (Hayhoe et al. 2007):

- *Improving farm management practice*
- *Increased focus on risk management and flexibility of production systems*
- *Diversification crop varieties and rotations*
- *Adjusting cropping seasons where possible*
- *Changing livestock breeds*
- *Improving farm technology.*

Effective adaptation is likely to prevent half of the losses in production otherwise predicted to occur as a result of climate change by 2030 (Hayhoe et al. 2007). Adaptation to climate change will require significant investment in R&D and extension to facilitate the development and adoption of new and improved and alternative farm practices and technology. This will require a turnaround in the current trend of declining public investment in agricultural R&D over the last three decades (Alston et al 2009). Adoption of changes in management and technology essential to effective adaptation to climate change will require continued investment in industry networks (including grower groups), and in industry-driven, relevant R&D. In particular, the developing and building on linkages between industry networks, R&D organisations networks, government investment programs and grower groups will be essential in achieving positive outcomes in development and adoption of successful adaptation programs.

1.2.3 Discussion

The effects of climate change on the agricultural sector are likely to be substantial in coming decades. The predicted impacts include reduced growing season rainfall, more frequent drought periods and more severe weather events throughout the region, leading to overall yield reductions and increased production risks.

Changes in demand for agricultural products as a result of a predicted slowdown in global economic activity are also likely. The dominant nature of agriculture within the regional economy means a slowdown will result in further negative socio-economic pressure throughout the region. Currently the socio-economic well-being of the region is largely dependent on the capacity of the agricultural industry to adapt to the changing environment.

Identifying and adopting improved management practice and farming techniques, improvements in technology and alternative breeds and varieties are essential components of adaptation to climate change. Effective adaptations to climate change will require significant investment in research and effective linkages between industry networks and R&D organisations (Hayhoe et al. 2007).

It is essential that R&D is driven by industry rather than by the scientific community, with science taking its lead from industry, to ensure that relevant and applied R&D programs actually deliver effective outcomes (Gunasekera et. al. 2007). Developing and maintaining linkages between industry, the scientific community, funding institutions and grower groups will be essential in achieving effective adaptation to climate change.

There is also a sense of urgency about responding to the challenges of a changing climate. All indications are that changes in global atmospheric conditions in South West WA are already influencing regional climatic conditions, driving an emerging financial crisis within the agricultural sector of the region.

1.3 Water Resources and Environmental Flows

1.3.1 Background

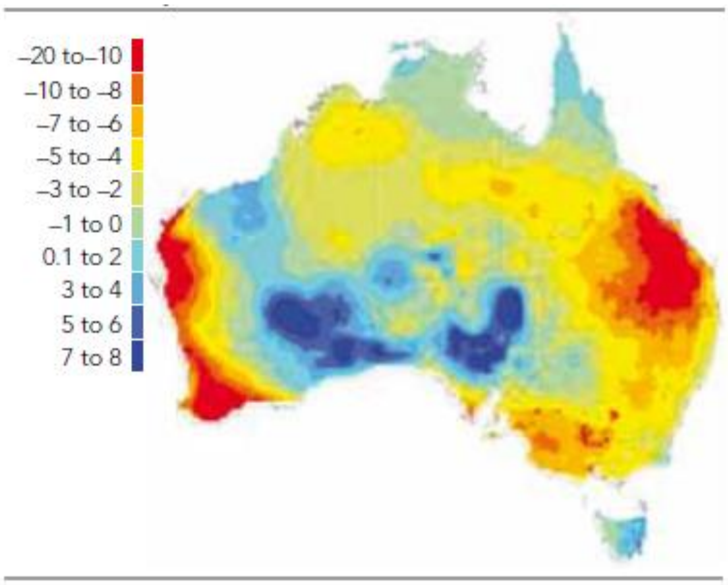
Access to reliable water resources within the ARB is essential to industry and urban populations. Water consumed within the region is a combination of that supplied through the Water Corporation's Integrated Water Supply Scheme (IWSS) – often referred to as *the scheme* and local water resources. The population and industry within the ARB consume between 10.3–13.0 GL (average 11.5 GL) from the IWSS annually. Residential and farm water use accounts for 42% and 38% of water demand respectively, with the remainder of water used principally for commercial and industrial users (9%) and for watering parks and gardens (5%). Not everybody within the region has access to scheme water, and many farmers and small landholders and some towns are self-sufficient in water (GHD 2008).

Water shortages, particularly within agricultural areas not serviced by the IWSS, have been relatively frequent in recent years, and lower than average rainfall throughout the ARB has put the focus onto the reliability of water resources.

1.3.2 Climate Impacts

Maintaining reliability of water resources within the region is going to be more difficult in the coming decades, based on current predictions of the future climate variability within the region. Increased temperatures are likely to result in increased demand, and predicted declining run-off within the region will test the reliability of current water resource infrastructure. Modelling undertaken by CSIRO indicates that the ARB is likely to experience a 10–20% reduction in run-off by 2030 (refer Figure 5).

Figure 5. Projected change in run-off by 2030 (Source CoA 2007).



Average sensitivity of Australian runoff to a 1°C increase in global temperature; based on a simple hydrological model, using twelve different climate model patterns, three climate sensitivities and three emissions scenarios.

Previous modelling undertaken by CSIRO (2008) indicates that run off within the region is extremely sensitive to changes in rainfall. The (LASCAM) modelling predicted that a 10% increase in rainfall would result in an up to 60% increase in run-off within the ARB, increasing average annual flows from 150 GL/year to 248 GL/year. CSIRO (2008) also predict that a 10% and 20% reduction in rainfall would result in a 40% and 55% reduction in flow in the Avon River respectively (GHD 2008 b).

The reliability of farm dams is predicted to decline from 93% currently to approximately 71% and 52%, assuming a 10% and 20% reduction in rainfall respectively (GHD 2008 b).

Modelling undertaken by CRIRO 2008 and GHD 2008b suggest that moderate declines in rainfall of around 10% may well result in catchments falling below a threshold for production of sufficient runoff to maintain water resources and environmental flows.

Significant investment in infrastructure will be required to maintain current levels of security of supply even assuming no increase in demand. However, the impacts of changing climate patterns may exert additional influence over agricultural demand for water use within the region, with increased temperatures and potential changes in agricultural enterprises leading to increased demands on water resources.

There has been only limited formal assessment of the potential impact of climate change on water resources within the region, but analysis undertaken to date indicates that climate change will significantly threaten the capacity of water resources within the region to meet demand.

1.3.3 Current trends

Previous investment through Farm and Community Water Grants offered by state and commonwealth governments has resulted in improved self-sufficiency for water supplies within the region. Investment through the Community Water Grants resulted in a 60% reduction in the 0.5 GL of water applied to parks and gardens and reserves within the region. The high uptake was probably due to the strongly economic nature of the investment, with a typically three to four year break-even period when discounted at 5% (GHD 2008). Development of agricultural water resources is unlikely to be as economically attractive, typically with an 8–10 year break-even period (GHD 2008).

Demand for water resources within the region is largely influenced by crop-spraying requirements and stock numbers. Whilst demand for stock water declined within the central and eastern sub-regions throughout the 1990s, there was a subsequent increase in demand for high quality water for crop spraying. Meanwhile, rainfall patterns have led to an increase in demand on all water resources, particularly since 2000, due to a series of poor rainfall seasons and changes in population. There has been a reduction in urban water demand (particularly within the eastern, central and southern sub-regions) due to decline in population, more than offset by a considerable increase in demand for water within the Avon Arc as a result of population growth exceeding 10% for the period 2000–2010 (GHD 2008, ABS 2011).

Trends indicate increasing water demand in the urban, commercial and industrial sectors within the Avon Arc and falling demand in the other sub-regions. Predicting future agricultural demand for water is much more complex. Agricultural water demand will be driven by the increasing water requirements of livestock in response to increased temperature. However, changes in livestock numbers within the region are difficult to predict, as they will be influenced by enterprise substitution driven by increasing risk associated with grain production but also predicted falling demand for livestock products within the medium term (Gunaskera et al 2007).

1.3.4 Impacts on environmental flows

A previous study estimated there are approximately 14,000 dams within the Avon Arc (11,800 km^2). It is estimated that farm dams currently capture approximately 14% of all run-off generated within the Avon Arc (GHD 2008 b).

The management response to the projected decline in dam reliability will have important implications for environmental flows within the region. An increase in dam storage associated with land use change and declining dam reliability associated with climate change, particularly within the Avon Arc, will reduce environmental flows (GHD 2008 b).

Increasing dam capacity to maintain dam reliability in response to a 10% reduction in rainfall would result in an increase in total surface water captured within the Avon Arc from 14% to 22% of total flow (GHD 2008 b). Constructing improved (roaded) catchments to increase run-off to farm dams both increases dam reliability and the frequency of dam overflow. GHD (2008b) study concluded that the addition of improved catchments would largely nullify the negative influence of farm dams over environmental river flows.

1.3.5 Discussion

Current trends in water demand include a shifting in demand from the east and central sub-region to the Avon Arc consistent with population trends and a slight decline in agricultural water demand throughout the region. Whilst future water demand within the Avon Arc is likely to increase in line with projected population growth, future water demand for agricultural water use is less clear, although there is some potential for increasing agricultural water demand at least in the short term.

There has been limited assessment to date of the extent to which climate change is likely to influence the capacity and reliability of water resources and environmental flows within the region. However, the work that has been undertaken suggests that climate change will have a dramatic influence over both environmental flows and the reliability of farm dams (GHD 2008, GHD 2008b). Climate modelling indicates that the Avon River basin will experience a reduction in rainfall of up to 15% by 2030. Rainfall–runoff analysis suggests that this could translate into around a 30% reduction in runoff (GHD 2008).

Strategies for overcoming potential reductions in dam reliability as a result of declining run-off may have cascading impacts on downstream environmental flows. Adoption of improved catchments is predicted to provide the most efficient and reliable mechanism for improving dam reliability, in addition to reducing the impact of increased dam storage on environmental flows (GHD 2008b).

If demand outstrips the supply of water within the region then water is directed preferentially to urban centres, thereby influencing supply to rural properties, and in particular standpipes used as emergency water supplies by many farmers not connected to the IWSS. Costs in providing emergency water supplies to the region are likely to increase in the coming decades as a consequence of climate change.

Professional capacity and investment constraints represent the major hurdles to the development of more effective water resources within the region. There is clearly a market failure in the water resources planning and design area within the region, exacerbated by state government agencies' withdrawal of services.

1.4 Native Vegetation

1.4.1 Background

Changing climate patterns are already impacting biodiversity at a global scale by modifying the geographic distribution of species (Fitzpatrick et al 2008). There is increasing evidence that Australia's biodiversity is experiencing impacts from climate change consistent with global trends, and that even with effective emission controls, past emissions will continue to contribute to unavoidable climate change over more than a century. It is therefore critical to understand the future impacts of climate change on biodiversity and undertake appropriate management actions where possible (Steffen et al 2009, Yates et al 2010b).

'Mediterranean' ecosystems are likely to be most affected by anthropogenic climate change and exhibit the highest level of confidence in rainfall predictions (Klausmeyer & Shaw 2009, Yates et al 2010b). It is predicted that the area of Mediterranean climate in Australia will contract by 23%–51% of its current size by 2100 (Klausmeyer & Shaw 2009).

1.4.2 Predicted Impacts

Exactly how climate change will impact the region's biodiversity is difficult to predict. Understanding impacts and developing appropriate management actions are complicated by a series of generally poorly understood factors, including (Steffen et al. 2009):

- *Climate change will interact with other drivers currently impacting biodiversity, including landscape fragmentation, introduced feral animals, introduced weeds and pathogens, modified fire regimes, and changes to landscape hydrology*
- *Changes to distribution and abundance of individual species are likely to create cascading influences throughout functional groups and ecosystems, potentially modifying entire systems in unpredictable ways*
- *Changes to average parameters may be less important than changes to extremes; for example, changes to extreme temperature may have a greater influence over survival of individuals and the structure and function of ecosystems than changes to average temperature*
- *We have limited knowledge about the thresholds, limiting factors, genetics, dispersal mechanisms and interactions between species that will be critical to understanding the nature and extent of impacts*
- *Management actions undertaken to adapt and/or mitigate the impacts of climate change on human systems may exacerbate impacts on biodiversity*.

Climate change will influence communities and entire ecosystems by restricting the distribution of individual species and/or interrupting interactions between species or other ecological processes. These interactions are often complex and impacts may result from cascading effects of seemingly minor changes combining into fundamental changes to the structure and function of ecosystems.

We currently have a limited capacity to understand the range of complex interactions that occur within ecosystems and how climate change is likely to influence communities and associated ecosystems. Most of the analysis undertaken to date has targeted the development of individual species and distribution models and assessment of the range and distribution of key species. Some examples of such analyses are presented below, providing an indication of the likely impact of climate change on key species and therefore an indication of the potential impact on the structure and function of underlying ecosystems within the Wheatbelt.

Some authors have already noticed a decline in the health and vigour of native vegetation within the Wheatbelt, particularly in woodlands. A study by Saunders et al (2002) found that remnant populations of salmon gums (*Eucalyptus salmonophloia*) and York gums (*E. loxophleba*) were degrading due to extended drought conditions, and predicted that only 11% of salmon gums and 17% of York gums in the remnant examined would survive until 2025, assuming current climatic conditions. Whilst this is not a definitive study of impact of drought on woodland communities, it does highlight that the impacts of extended drought and declining rainfall on the health of woodland communities at a local scale is already occurring. However, the decline of woodland communities is not just as a result of declining rainfall. Grazing by domestic stock and rabbits, weed infestation and the absence of appropriate fire regimes is also limiting the capacity of salmon gum and other woodland ecosystems to regenerate, further threatening their longer-term health and well-being (Dorrough & Moxam 2004, Shedley 2007).

Species distribution modelling undertaken to date indicates that the impacts of climate change on native vegetation will be considerable. The modelling considered the impact of three future climate scenarios on the survival of 100 banksia species, based on their ability to migrate to suitable habitat (Saunders et al. 2002). Across all climate scenarios tested, the range of two thirds of species tested was found to decline and only 6% of species were projected to expand their range. The analysis also predicted that 5–25% of banksia species tested would become extinct by 2080. Species loss was driven primarily by changes in precipitation, with the greatest loss predicted to occur in the transition zone between the wet coastal and interior arid regions (i.e., the ARB). The range of most species appeared to collapse under all climate scenarios, indicating that species loss will occur even under relatively optimistic climate change assumptions (Saunders et al. 2002).

Another study undertaken by Yates et al. (2010a) found similar results when predicting the fate of 18 Banksia species for a range of climate scenarios by 2070. The 18 species were chosen to reflect the biogeography of Banksia in the Southwest Australian Floristic Region (SWAFR). The analysis found that the predominant response to all climate change scenarios was species range contraction, with exemptions for some northern and widespread species. Increased climate change severity was found to greatly increase the risk of decline in all 18 species of Banksia tested (Yates et al 2010a).

1.4.3 Discussion

The indications suggest that climate change impact on native vegetation within the Avon River basin over the next century will be dramatic and devastating. When combined with the other stressors that are a legacy of European occupation of South West WA, climate change clearly has the potential to severely impact the distribution of many of our species. This may in turn result in cascading impacts, destabilising underlying functional ecosystems. However, all native vegetation has a degree of resilience to variations in climate and other stressors. The situation is highly complex, with a range of interconnected ecological communities responding differently to the range of overlapping stressors and external shocks, often exacerbated by adjacent land use.

Adaptation of species to climate change, and other stressors for that matter, occurs through a range of mechanisms including, phenotypic plasticity, evolution and migration. Migration is considered by most authors likely to be the most effective mechanism most species can employ to adapt to a rapidly changing environment, with phenotypic plasticity ultimately limited by underlying genetic encoding and evolution and shifting genetics only likely to occur in species with very brief life cycles (Fitzpatrick et al 2008, Steffen et al 2009, Noss 2010).

Migration of many species within our landscape is currently greatly impeded by landscape fragmentation resulting from extensive clearing of native vegetation within agricultural areas of the region. Development of corridors and increasing landscape permeability improves linkages between functional units of native vegetation to assist in migration of species, and is likely to be an important tool for assisting landscape adaption to the projected impacts of climate change. However, the effectiveness of corridors in assisting migration of species through dispersal is generally not well understood and investment in developing corridors needs to be accompanied by effective scientific analysis of their efficacy and interaction with other changes to landscape management practice.

It is likely that the effectiveness of corridors will be largely dependent on the dimensions and nature of individual corridors, including habitat choice, dispersal capacity and individual area requirements of target species. In addition, the degree of habitat fragmentation, scale of habitat heterogeneity, and nature of adjacent land use are important factors influencing the effectiveness of corridors. Certainly the development of effective corridors is a complex undertaking, and will require a concerted scientific approach ongoing assessment of their effectiveness under a range of conditions with a strong emphasis on the principles of adaptive management.

Even if corridors prove effective in aiding dispersal of species within our changing landscape, many species may require assisted migration, particularly larger species with long life cycles. Once again, translocation of species within the landscape is a complex undertaking, and the effectiveness or otherwise of assisted migration will depend on a range of factors including our understanding of habitat requirements of individual species, the nature of interactions with other species and impacts on communities and other trophic levels, capacity to predict the extent, rate and nature of our changing climate, and understanding the likely impact of introducing new genetic material into existing habitats. A considered scientific approach is required, based on the principles of adaptive management, to ensure that we learn from our own and others' experience.

Additional strategies for maintaining biodiversity under a changing climate conditions will be further enhanced by (Noss 2010):

- *Maintaining vegetation associations across environmental gradients in reserves and other areas of conservation*
- *Protecting climatic refugia at multiple scales*
- *Limiting fragmentation and providing connectivity, especially parallel to climatic gradients*
- *Providing buffer zones for adjustment of reserve boundaries*
- *Maintaining natural fire regimes*
- *Maintaining diverse gene pools*
- *Identifying protected functional ecosystem groups and assemblages and keystone species.*

Developing and maintaining effective linkages within the scientific and research community will be essential in managing the impact of climate change on native vegetation due to the underlying complexity and uncertainty associated with implementing effective strategies. Effective and extensive linkages with the regional community will be essential in delivering the landscape-scale response demanded by the predicted impacts of climate change. In addition, all land managers within the region – including farmers, the Department of Environment and Conservation and representatives of NGOs – need to work together, sharing information and resources, for us to achieve our objective of conservation management under the predicted adverse conditions.

The scale, nature and uncertainty of potential changes to our environment calls for a sophisticated, cooperative and multidimensional approach, based on the principles of adaptive management, underpinned by good science, supported by effective partnerships and delivered through a spirit of cooperation and support.

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