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**Adapting to climate change for water  
resource management: Issues for northern  
Australia**

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*Lake Argyle Western Australia, (photo courtesy of Aimee Nygaard)*

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## Executive Summary

There are two aims of this work focused across northern Australia (north of the tropic of Capricorn). First is to identify adaptive strategies to deal with climate change in each jurisdiction. Second the work identifies issues for adaptation in water resource management across the region in light of potential impacts and local conditions. Over half of Australia's annual runoff occurs in the north Australian region from November to April. The region is relatively undeveloped and sparsely populated compared to southern Australia. Almost 30% of the land base is owned under Indigenous tenure. Drought and over-allocation of water resources in southern Australia has focused attention on the potential for expanding irrigated agriculture in the north. With an outlook for increased drought in southern Australia the pressure to look north is likely to increase. While rainfall projections in northern Australia are identified as stable to increasing, our research highlights that the outlook for water availability remains uncertain under climate change scenarios across the north.

Work by CSIRO and BOM (2007a) and CSIRO (2009a) predict that to 2030 and 2070, northern Australia is likely to experience hotter temperatures, more intense rainfall and more intense cyclonic events. It must be stated that climate change impacts are likely to vary across the region and impacts may be highly localized. There may be an increased risk of saltwater inundation and erosion in coastal areas. While inland areas may experience more extreme high temperatures, drought, flooding, dust storms and bushfires (CSIRO, 2009a; Green, 2006). Although northern Australia produces over half of Australia's runoff, it is considered to be water limited for two main reasons. First there is high evaporation and evapotranspiration for most of the year (CSIRO, 2009a). Second the potential for water storages is constrained (NAWLT, 2009; Petheram et al, 2008). There may be consequences for water resources from climate change (as well as infrastructure) which combined with increased population growth (especially in Darwin, NT) could make water stress more acute, particularly during the dry season. As water stress increases the need for a robust and adaptive framework to manage water becomes more important. Climate models may allow policy makers to anticipate particular events in setting design standards for water infrastructure (Hallegatte, 2009).

Reference has been made in water plans to climate change in each jurisdiction. There is also recognition in climate adaptation strategies that water resources will be impacted by climate change. Adaptation for water resource managers and policy makers is not new. But the effects from climate change may impose new and perhaps unforeseen challenges on water management regimes. This is particularly true across tropical northern Australia, a region already difficult to manage and deliver services to because of its size, remoteness and relatively poor infrastructure base. It is recommended in literature that adaptation for water resources should consider basins in an integrated way and address issues such as flood and drought protection, managing water demand, and maintaining and protecting infrastructure. Water markets are a demand side strategy to adapt to climate change. Markets have enabled irrigators in southern Australia the flexibility to cope with drought

and maintain productivity during water shortages. Water markets may enable adaptation to the effects of climate change by allowing re-allocation among users and flexibility to users through trading. Markets can also encourage water use efficiency which is important where climate change reduces water availability. The use of water markets are at a formative stage across the north Australian region, with little to no trading at the time of writing. Despite no trading, northern jurisdictions generally allow water trading to occur in areas subject to a water plan (competition for water tends to be higher in these areas and necessitates a plan).

Water plans seek to identify a sustainable level of consumptive extraction by using best available science and community consultation to support economic, ecological and social outcomes. It is acknowledged across the north that data relating to water resources and climate is limited. This is particularly true for groundwater resources for which there is a strong reliance across much of the north. There is considerable risk for the extraction on groundwater resources on groundwater dependent ecosystems, and on the customary values of Indigenous Australians. The Northern Territory has in place one water allocation plan in the region, the Tindall aquifer plan. Queensland has the Gulf and Mitchell resource operation plans. Western Australia has the Ord River water management plan. The Tindall plan in the NT is the only groundwater plan completed in the region. In Queensland and the NT plans are enshrined in statute and last 10 years (though in the NT the plan is reviewed within 5 years). While in WA the Ord plan is for 3 years.

An important tool for adapting to climate change in water plans is the ability to reduce water allocations to entitlement holders in line with reductions in water availability. This is often done according to the level of security provided to an entitlement holder (high, medium and low security). The economic value of entitlements is linked to its level of security. In the Northern Territory, the Tindall aquifer water allocation plan provides that all water licenses may have their allocation reduced to zero in serious drought (commencing with low then up to high security). In times of critical water shortage the Water Controller in the NT has the power to impose restrictions on stock and domestic use as well. In the Ord there is greater security afforded to users because of the storage capacity in Lake Argyle (101 GL). Allocations in the Ord are determined based on water storage levels in the dam, and restrictions can be imposed on allocations if water reaches 'critical levels'. It is expected that in only 5 years out of every 100 will water reach 'critical levels' and allocations be reduced. Hence entitlement holders will get their full allocation 95% of the time. Plans are reviewed and new information may be integrated and entitlements amended to reflect any changes in water availability.

Most work on climate change and hydrology research has been focused on metropolitan centres in WA and Queensland. There has been relatively little work across the north to understand the effect of climate change on water resources. Uncertainty and lack of knowledge serve to constrain planning efforts. Adapting to climate change in water resource management requires an integrated approach, coordinating efforts across government and collaborating with stakeholders to be effective- it will be important to support socio-economic outcomes over the long term. The impacts from climate change will not be distributed equitably and will have implications for Indigenous groups (who are disadvantaged), with consequences for health, wellbeing and livelihoods (Green,

2006). Industry will be affected by the impacts of climate change in northern Australia. For example, the pastoral industry which covers almost 90% of land use could be negatively affected by reduced feed quality and water availability. These impacts can be mitigated by proactive planning, as well as collaborative and stakeholder focused planning activities. Planning will require particular effort to include and engage Indigenous groups, where consultation efforts have in the past fallen short of expectations in water management.

## **Acknowledgements**

We acknowledge the support of the Environmental Economics Research Hub which supported this research.

## List of Abbreviations and Acronyms

COAG	Council of Australian Governments
CTH	Commonwealth
DERM	Dept. of Environment and Resource Management (QLD)
NRETAS	Dept. of Natural Resources, Environment, The Arts and Sport (NT)
NT	Northern Territory
NWC	National Water Commission
NWI	National Water Initiative
QLD	Queensland
ROP	Resource Operations Plan (QLD)
WA	Western Australia
WAP	Water Allocation Plan
WRMU	Water Resource Management Unit (WA)
WRP	Water Resources Plan (QLD)

## Glossary

**Aquifer:** An underground (geologic) formation which is capable of holding water and through which water can percolate. Aquifers are capable of yielding quantities of groundwater for consumptive use.

**Cap:** An upper limit for the volume of water available for use from a waterway, catchment, basin or aquifer.

**Consumptive pool:** The volume of water resource that can be made available for consumptive use in a given water system under the rules of the relevant water plan.

**Consumptive Use:** Use of water for consumptive purposes including irrigation, industry, urban and stock and domestic use.

**Regulated system:** River system where the flow of the river is regulated through the operation of large dams or weirs.

**Supplemented water:** Term used in Queensland to describe water provided through the irrigation system, that is, water which is captured and then released on demand from the irrigation system storages.

**Unregulated system:** River system where flows are not regulated by the operation of structures such as major dams or weirs.

**Unsupplemented supply:** Term used in Queensland for natural stream flow that is not reliant on water infrastructure.

**Water access entitlement:** A perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan.

**Water allocation:** The specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan.

**Water plan:** A statutory plan for surface and for groundwater systems that is consistent with the regional natural resource management plans, and that is developed in consultation with all relevant stakeholders on the basis of the best scientific and socio-economic assessment to provide secure ecological outcomes and resource security for water users.

# 1. Introduction

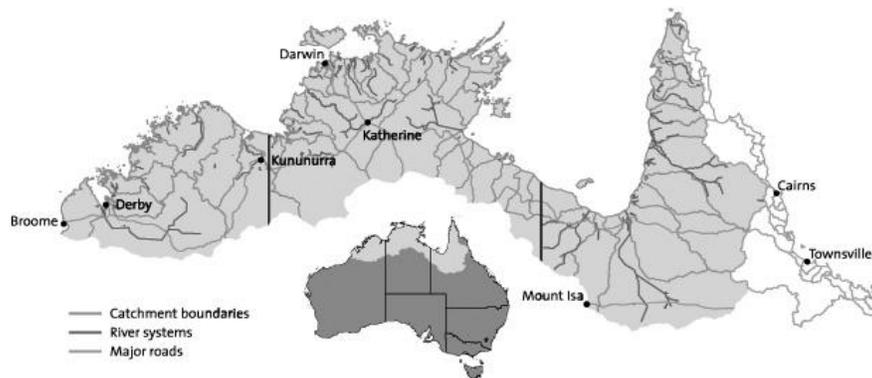
## 1.1 Aims

The aim of this study is to identify the adaptive strategies present in water market frameworks across northern Australia. After preliminary examination it was found that agencies had planned for climate change to provide more water in the future, and in jurisdictions the potential to reduce allocations exists if water availability is reduced in the season. Research from CSIRO (2007a, 2007b, 2010a, 2010b) suggests that climate change would increase temperatures and evapotranspiration to 2050 and 2070. This combined with projected higher population projections suggests there would likely be an increase in water stress at certain times of the year and the need for adaptive planning. This is particularly important because of equity issues related to Indigenous rights and interests and the environment. There is also the increased likelihood of storm surges and cyclonic activity that will also have implications on water management. We present adaptive approaches, informed by comparative literature.

## 1.2 Background

Northern Australia is made up of three jurisdictions: the two states of Queensland and Western Australia (WA), and the Northern Territory (NT) (See Figure 1).

**Figure 1:** Map of study region (source: TRaCK)



As a region, northern Australia comprises a quarter of the Australian land estate, but makes up only 2% of the population (about 310,000 people), with approximately a third of the population identifying as Indigenous (Carson et al, 2009). Overall, the people in this region are more likely to be male, indigenous and young than the broader Australian population; people are also becoming more likely to live in urban centers such as Darwin, Broome and Mt. Isa (Carson et al, 2009). It is predicted that the current trend of

increasing population growth and urbanisation will continue in the future (Carson et al, 2009). Thirty percent of the north Australia’s land base is owned by diverse Indigenous peoples (Altman et al, 2009). This land is owned under a variety of tenures, much of it communally in trust.

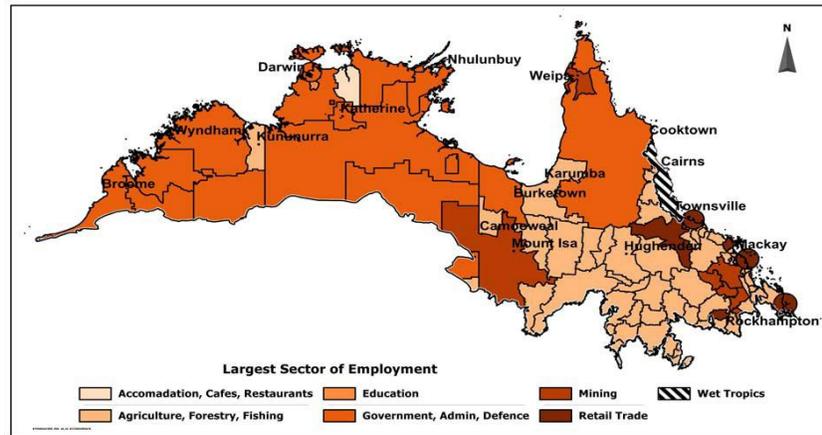
The table below illustrates the regional variations in population growth rates across the north to 2026. It is anticipated that the current population growth rates will continue for at least the next sixteen years, with a projected population of nearly half a million people by 2026.

**Table 1:** Summary of TRaCK regional population projection results, 2006 to 2026. (Carson et al, 2009: 27)

	2006	2011	2016	2021	2026	Growth 2006 to 2026	Av. annual growth rate 2006 to 2026
<b>Indigenous</b>							
TRaCK region	80,287	88,025	96,916	107,180	119,081	39.4%	1.97%
Northern Territory TRaCK area	38,498	42,846	47,684	53,069	59,063	42.8%	2.14%
Queensland TRaCK area	27,526	29,568	31,762	34,118	36,649	28.6%	1.43%
Western Australia TRaCK area	12,933	13,545	14,187	14,861	15,568	18.5%	0.93%
<b>Non-Indigenous</b>							
TRaCK region	229,853	244,809	265,046	292,081	327,938	35.5%	1.78%
Northern Territory TRaCK area	111,089	116,614	122,416	128,509	134,906	19.4%	0.97%
Queensland TRaCK area	104,722	108,200	111,806	115,544	119,419	13.1%	0.66%
Western Australia TRaCK area	15,365	17,091	19,011	21,146	23,522	42.6%	2.13%
<b>Total persons</b>							
TRaCK region	310,140	332,834	361,963	399,261	447,019	36.6%	1.83%
Northern Territory TRaCK area	149,587	159,460	170,101	181,578	193,968	26.0%	1.30%
Queensland TRaCK area	132,248	137,768	143,568	149,662	156,068	16.6%	0.83%
Western Australia TRaCK area	28,298	30,636	33,198	36,007	39,090	32.3%	1.62%

Within this population, employment by sector shows a great deal of regional variation, illustrated in Fig. 2. The largest sector in terms of employment across two thirds of the geographic region is government, while major contributors to Gross Domestic Product (GDP), such as mining, are less vital. Stoeckl et al, (2007) suggest that mining is more of an enclave industry, acting as a significant employment source in certain areas, such as Mt. Isa. The majority of non-government regions are dominated by agricultural employment.

**Figure 2:** Largest sector of employment in the region—by postcode (Stoeckl et al, 2007: 38)



About half of Australia’s total stream-flow occurs in northern Australia (200,000 GL) but often this is highly variable, with some 94% of northern Australia’s rainfall occurring between November to April (Creswell et al, 2009). Creswell et al, (2009) point out that given the variability, the connection between groundwater and surface water is important for dry season flows. There are three main drainage divisions for northern flowing rivers (see Table 1) containing thirteen river basin regions. These include:

**Table 2:** Drainage divisions and river basins across the north

<u>Drainage Division</u>	<u>River Basin Region</u>
Timor Sea:	Fitzroy (WA), Kimberley, Ord-Bonaparte, Daly, Van Diemen, and Arafura.
Gulf of Carpentaria:	Roper, South-West Gulf, Flinders-Leichardt, South-East Gulf, Mitchell, Western Cape.
Northern North-East Coast:	Northern Coral.

The study region for this project encompasses a vast and diverse geographic area, from Cairns in the east to the Kimberley in the west. The river flow is highly seasonal and surface flow often ephemeral, where during the dry season many rivers do not flow at all (CSIRO, 2009a). In many areas the coastal edge of Northern Australia is lush and characterized by a tropical savannah climate, although Cape York exhibits both tropical and monsoonal climates. Moving southward the tropical savannah gives way to grasslands in most areas, and eventually to deserts in the far south (CSIRO, 2009a). The landscape of the north is one of vast expanses of escarpments and tablelands in the west. These relatively low lying lands rise sharply to meet the Arnhem Land plateau, a vast sandstone tableland stretching to the Gulf of Carpentaria (CSIRO, 2009a).

Within the 1 247 000 km<sup>2</sup> of river drainage area, much of the native grasslands remain intact, with intensive land use or clearing affecting less than 1% of the area (CSIRO, 2009a). The greatest land use in the North is pastoralism, although the greatest proportion of GDP is from the mining industry, and to a lesser extent commercial fishing. There is a significant area of the North conserved for aboriginal land use and conservation, Kakadu National Park and the Wet Tropics being notable examples. Around 30% of land in northern Australia is Aboriginal land owned under a variety of tenures (Altman et al, 2009). Landscape management for millennia was carried out by aboriginal peoples using strategically set fires (Whitehead et al, 2009; Woinarski, 2001). This continues to some extent, but there is a notable lack of sustainable fire management policy and coordination which can increase fire intensity and destruction, especially when compounded by the impact of introduced species such as buffel grass (CSIRO, 2009a). There are attempts to abate carbon on Indigenous land in West Arnhem Land under the West Arnhem Land Fire Abatement project, a private agreement between ConocoPhillips and Indigenous groups (Whitehead et al, 2009). Table 3 below identifies water availability, water use, population and land use across the region.

**Table 3:** Drainage division profile (collated from CSIRO, 2009a and CSIRO, BOM and BRS, 2010a,b)

	<b>Timor Sea</b>	<b>Gulf</b>	<b>Northern North East</b>
Jurisdictions	NT and WA	NT and QLD	QLD
Population**	164, 436	55, 788	N/A
Size (km2)	564,600	647,000	50,000*
Temperature average for year	28 c	28c*	28c
Run off (GL)**	70, 609	75,058	N/A
Stream flow per year (GL)	90,000	90,000	17,000
Precipitation (mm) (mean)	868 <i>1687 in north</i> <i>383 in south</i>	900mm <i>1800 mm in north</i> <i>300 mm in south</i>	1338
Historical mean evapotranspiration (mm)	1979	Considered to be higher than precipitation.	1853
Storage capacity (ML) **	>11,234,871	780,623	N/A
Water use (GL)**	270	250	N/A
Irrigated agriculture use (GL) **	>216	136	N/A
Irrigated land (km2) **	291	179	N/A
Pasture (km2) **	145,172	126,935	N/A

\* Approximate average \*\* (CSIRO, BOM and BRS 2010a,b).

In the Timor Sea and Gulf drainage division the area cleared is <1 % and most rain falls in estuaries and not in headwaters- restricting the potential for storages (CSIRO 2009a). This is not the case in the North East, where substantial rain falls in the headwaters (CSIRO 2009a).

### **1.2.1 Future Development**

The expansion of agriculture across the north Australian region has been highly anticipated for many Australians (Pigram, 2006). Queensland alone has 45% of Australia's surface water run off, much of this in the north and much of it undeveloped (Pigram, 2006). The North Australian Land and Water Taskforce (2009) estimates the potential for growth in irrigable land to be 100 to 200 percent (or 20 to 40,000 hectares). There has been a flurry of research activity recently examining the potential of northern Australia for irrigated agriculture, these projects include the Northern Australian Land and Water Taskforce (directed by the Federal Office of Northern Australia), Northern Australian Irrigation Futures (which identified the potential for an irrigation mosaic model) and Northern Australia Water Futures Assessment (the first part is the Northern Australia Sustainable Yields Project conducted by the CSIRO). There is also the environmental research hub Tropical Rivers and Coastal Knowledge (TRaCK) which is exploring the biological, ecological and physical attributes of northern Australia's freshwater resources. These assessments were spurred on in part by a national water reform process entitled the National Water Initiative (NWI) (2004), an intergovernmental agreement which sought to create a national standard in water resource management.

### **1.3 National Water Reform- the National Water Initiative**

In 1994 the Council of Australian Governments (COAG) proposed a Water Reform Framework which sought to encourage a common approach to water management, and to develop the institutional underpinnings of water markets. Increased water stress brought about by over-allocation, periods of drought, climate change, population growth and environmental degradation in southern Australia, provided the impetus for further national water reform, culminating in the NWI (2004) (Grafton and Peterson, 2007). It is important to emphasize that the NWI is a commitment by all state and territory governments in Australia to meet the objectives set out in the NWI.

The central aim of the NWI is to establish uniform regulatory and planning frameworks for surface water and groundwater across Australia and understand their interconnectivity. Social, environmental and customary issues are to be considered in water management through planning mechanisms. The planning framework is an important objective under the NWI to achieve sustainable levels of water extraction (Gentle and Olszak, 2007). Importantly for Indigenous people across northern Australia, paragraphs 52-54 in the NWI address recognition of 'Indigenous Access to Water.' These paragraphs provide that where possible Indigenous people should be involved in developing water plans and Indigenous customary water uses must be accounted for.

Other commitments made under the NWI (2004) include:

- The creation of statutory water plans that provide sufficient water for the environment;
- Overcome barriers to enable trade in water through the creation of entitlements and a risk sharing framework for variability in water availability;
- Develop standards on water accounting, entitlement registers and water meters; and,
- Encourage best practice pricing (actual cost of storage and delivery).

The creation of water markets are a central platform of the NWI;<sup>1</sup> and the development of water markets has been a success story in southern Australia where almost all water transactions occur (NWC, 2008). Across northern Australia a lack of demand and sufficient water availability have not created the conditions to encourage water trading to date. However, the ability to trade exists in all jurisdictions in the north.

## **1.4 Institutional Setting**

Each state and territory has vesting legislation which assigns rights to water to the Crown (see Table 2). The institutional, regulatory and legislative framework for water resource management in jurisdictions across northern Australia is complex (Stoeckl et al, 2006; Hegarty et al, 2005). These systems have developed independently to meet the specific needs of each jurisdiction and are influenced by physical features, economic considerations, political climate, community attitudes, and the existing legal and institutional framework. Each jurisdiction has its own arrangements and different terminology, which can make comparison difficult. In this report we use NWI consistent terminology but will refer to each jurisdictions terminology when analyzing that specific jurisdiction. Queensland for example uses ‘supplemented’ to identify whether a system has infrastructure to store and/or distribute water to users; and ‘unsupplemented’ where users self supply (while NWI terminology and that used in NT and WA is regulated/unregulated).

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<sup>1</sup> The potential to trade water has existed in certain states in Australia since the 1980’s to encourage trading (Brooks and Harris, 2008).

**Table 4: Institutional Arrangements for water in jurisdictions**

	<b>Northern Territory</b>	<b>Queensland</b>	<b>Western Australia</b>
<b>Legislation</b>	<i>Water Act</i> (1992) (amended 2004)	<i>Water Act</i> (2000)	<i>Rights in Water and Irrigation Act</i> (1914) (RIWI Act)
<b>Regulation</b>		Water Regulations 2002	<i>Rights in Water Irrigation Regulations 2000</i> (WA)
<b>Policies for water trading</b>	80-20 guideline which provides that 80 % of a system be set aside for the environment and 20% for consumptive use		Operational policy 5.13- provides for water entitlement transactions for WA
<b>Institutions charged with water management</b>	Department of Natural Resources, Environment, the Arts (NRETA)	Department of Environment and Resource Management (DERM)	Department of Water
<b>Officials responsible for management and allocation of water</b>	Controller of Water Resources advises and reports to the responsible Minister, and issues, transfers and amends licenses	At direction of its Minister and Chief Executive Officer	Minister for Water Resources

### **Northern Territory**

The *Water Act* (1992) (amended in 2004), provides the legislative underpinning for water management in the NT. The *Water Act* sets the rules for licensing of groundwater and surface water extraction as well as provides for trading. The Department of Natural Resources, Environment, the Arts (NRETA) is responsible for administering the Water Act, and a Controller of Water Resources advises and reports to the responsible Minister, and issues, transfers and amends licenses. Trading can only occur within a Water Control District which is declared by a Minister when there is sufficient need to do so (i.e. reaching full allocation). Currently there are six Water Control Districts in the NT and three finalized Water Allocation Plans, which sets the general trading rules. There is one finalized plan in place in the study region of northern Australia, the Tindall aquifer in Katherine. There are also draft water plans to be prepared for the Ooloo aquifer and Mataranka region. While trading can occur in all regions, there have been no transactions to date.

The protection of natural and cultural values is acknowledged as important in NT water resource management (Northern Territory Government, 2009). This is reflected in the policy approach to allocations- an 80/20 guideline. This approach seeks to set aside 80%

of a system for cultural and ecological (or non consumptive) uses; while 20% can be allocated for consumptive use.

## Queensland

The *Water Act* (2000) provides for the management of Queensland's water resources, outlining the planning, risk sharing and trading framework. The Department of Environment and Resource Management (DERM) undertakes water planning and administers the licensing and entitlement regime. In supplemented schemes (or regulated systems) DERM administers the resource operations licenses which allow Sunwater (a government business enterprise) to operate infrastructure. Trade in unsupplemented areas (like in much of northern Australia) requires DERM approval.

DERM has a two-tiered water planning framework in place. The first tier is the Water Resources Plan (WRP) which is 10 years in length. The WRP identifies the volume of water resources available for consumptive and non consumptive uses in the catchment. Compensation is payable to entitlement holders if the plans are changed before 10 years and the value is affected. The Resources Operations Plan (ROP) converts existing water licenses and interim water allocations to tradable water allocations, and this process involves unbundling land and water title and defines the trading rules for the scheme. Allocations in supplemented schemes are accorded high, medium and low security status. High priority water is generally for drinking supplies (and sometimes mines) and medium security to irrigation. Information on allocations is recorded on a register.<sup>2</sup> Queensland has more water storages than its counterparts in northern Australia. The amount of water available to allocation holders in supplemented schemes is determined according to a water sharing index. This index is the mean of the percentage of number of months in the simulation period (a historic period) for each priority group that allocations are fully supplied. In supplemented schemes there is a contractual relationship between allocation holders and Sunwater (a government business enterprise) that is ongoing.

In 2007-8 there were 3.6 GL of water entitlements issued in Queensland, with 75, 968 ML of trade, a value of \$57.7 M, of which 44.5% was part of a property sale (NWC, 2008). Little of this occurred in the tropical northern belt.

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<sup>2</sup> Water entitlements that are converted under the ROP are recorded on the Water Allocations Register. This register records details such as the holder/s of the water allocation, tenancy arrangements, location, purpose, conditions and nominal volume. For supplemented water allocations it will also record the relevant resource operations license and the priority group. For unsupplemented allocations it details the water management area, extraction rate, flow conditions, volumetric limit and water allocation group.

## **Western Australia**

The *Rights in Water and Irrigation Act* (1914) (RIWI Act) provides the framework for water management. The Rights in Water and Regulations 2000 (WA) supports this Act. Operational policy 5.13 provides for water entitlement transactions. Before trade can occur the seller must hold a valid, tradable license. To be eligible for a license, persons must have access to land. Only volumetric licenses can be traded to another party who holds land. Licenses may be traded temporarily or permanently in part or whole (this may only occur through a land sale).

The Department of Water is responsible for administering the RIWI Act, and provides approvals to trade. Trade must occur within water resource management units (WRMU) that generally cover a basin or aquifer. In 2008 there are 45 groundwater and 51 surface water management areas in the state (NWC, 2008). A category is applied to systems in the north based on the level of allocation to consumptive uses. Commencing at C1, where 25% of the consumptive pool is allocated, trading is not likely to occur until allocation reaches C3 (75%) to C4 (100%) which is full allocation of the consumptive pool. As the level of allocation increases towards C4 there is more research conducted and allocation limits may be adjusted accordingly.

Water planning occurs at a State, Regional and local area Management Plan level. The Ord River Surface Water plan is the only operational plan in the study region. Lake Ord has a capacity of 101 GL and allocations are determined on flow data, ecological water requirements and storage capacity. A reliable supply is determined for irrigators with full allocations in 95 years out of 100 years. A Kimberley-wide Regional Plan is being developed, which identifies broad principles of development and water use across the region.

In 2007-8 there were 2.5 GL of water licenses issued in WA, with trade of 486 ML mostly concentrated in the south west of the state (with a value of about \$1 M), and 57 % of water trade was associated with a property sale (NWC, 2008). No water trading has occurred in the north, though the potential exists through the Ord Irrigation Cooperative, between members of the Cooperative. The amount of water available to members is based on areas they own under irrigation (about 17 ML per hectare). The level of security is high to members, with access to full allocation provided in 95 years out of 100 (95% security).

## **National Water Commission**

Under the NWI each jurisdiction has committed to reform water management to NWI standards. The National Water Commission (NWC) was established to drive and assess

the pace of reform.<sup>3</sup> The *Biennial Assessment of Progress in Implementation of the National Water Initiative* (NWC, 2008; 2009a) provides analysis on jurisdiction performance. Trading statistics are summarized in the *Australian Water Markets Report, 2007-2008* (NWC, 2008). The NWC has identified concerns around Indigenous access to water (NWC, 2009a) and the level of science informing water planning (NWC, 2008). For instance, “Outside the MDB, planning and entitlement reforms need to be pushed along to develop new and expanded markets for water” (NWC, 2009a: x).

## **Water Markets**

Over the last three decades water planners and policy makers have put more focus on demand based strategies to deal with water scarcity. Part of this approach has been the use of market based instruments to improve water use efficiency and productivity (Gleick, 2003). Water markets enable the lease, amalgamation or transfer of whole or part of water access entitlements or allocations. The use of market based approaches to re-allocate water among users has been successfully implemented in jurisdictions such as Chile, Australia and southern US states where agricultural and urban water supplies are constrained (Bauer, 2004; Bjornlund, 2004; Crase et al, 2004; Howe et al, 1986; NWC, 2009a; Pigram, 1993; Saliba, 1987). On a global scale, however, the use of water markets remains insignificant (Hadjigeorgalis, 2009).

The Australian water market is composed of discrete areas of trade defined by administrative or geographic boundaries. About 98% of trade occurs in the states of NSW, Victoria and South Australia, with the level of trade in water growing by 95% from 2007-8 to 2008-9 to \$2.2 billion. Much of this value increase has been in terms of water access entitlements (NWC, 2009b). During drought in southern Australia water markets were seen to offer flexibility to water users and reduced the impact of structural adjustment (Bjornlund, 2004; NWC, 2009). While markets may be efficient in allocating water among users, there is also the potential for third party impacts and social, ecological and political considerations must be recognized in trading rules and regulations (Chong and Sunding, 2006; Pigram, 1993). McKay and Bjornlund (2001) suggest that markets create sustainability and social justice challenges, and this issue becomes more acute across north Australia where Indigenous Australians are subject to a chronic socioeconomic disadvantage. There is limited awareness among the Indigenous population of water markets and there has been minimal Indigenous involvement in water reform (Jackson and Morrison, 2007).

For water markets to be effective there are significant knowledge gaps that must be filled to support efficacy (particularly in terms of ecological and social outcomes). For example,

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<sup>3</sup> The enabling Act for the NWC is the National Water Commission Act 2004, which provides for the NWC to advise COAG and the Commonwealth government on national water resource issues and of state progress against the NWI.

Grafton and Peterson (2007) identify the need required for greater understanding around flow regime and ecological considerations, social impacts from trade, water pricing and transaction costs. Across northern Australia groundwater is not well understood (despite its importance), further work is required to assess the customary and ecological implications of extractions (Stoeckl et al, 2006; Straton et al, 2009). However, the NWC notes that considerable progress has been made in reform since the implementation of the NWI, particularly in the development of plans and markets (NWC, 2009a).

## **2. Climate Change**

Over the last century there has been a measurable increase in global warming due to climate change, very likely brought about by human activity (Australian Academy of Science, 2010; IPCC, 2007a). Elevated levels of atmospheric greenhouse gases are the prime contributor to climate change, and climate models indicate reducing emissions will concurrently slow down global warming and its related impacts (IPCC, 2007a). Broadly, across Australia, climate change is expected to increase temperatures, reduce rainfall and increase the intensity of weather events such as cyclones and drought- this may likely reduce water availability (Newton, 2009). While there is wide variation in the regional impacts of climate change across the world, and in Australia, adaptation to climate change impacts is recognized as a fundamental aspect of current and future human development (Garnaut, 2008).

### ***Year and Scenario Projections***

The climate change scenarios used in this report are derived from climate change simulations for 2030, 2050 and 2070 produced by the Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Bureau of Meteorology (BOM) (CSIRO and BOM, 2007a). This online information will be supplemented by the Technical Report released by CSIRO and BOM (2007b). These Australia specific projections are based upon 23 global circulation models developed by the Intergovernmental Panel on Climate Change (IPCC, 2007d). While these projections cannot provide exact knowledge about future climate change and its impacts, they do allow best estimates within a measured range of uncertainty of possible futures. Low, mid and high emissions scenarios will be used to allow comparison of potential climatic situations across these time periods. Although variation from 10<sup>th</sup> to 90<sup>th</sup> percentiles are also provided online, the 50<sup>th</sup> percentile projections will be used here as illustrative of the best estimate. Also, annual projections will be used here, although seasonal variations are also provided online. The intent is to illustrate what kinds of broad climate changes could be possible in the future of northern Australia.

The time period up to 2030 will see little variation from predicted mid-range climate impacts as atmospheric gases impacting the climate for the next twenty years have already been released. The emphasis up to this point is on adaptation to impacts at the projected mid-range emission level, so while low and high emissions scenarios are

presented in this report, the mid emission scenario (IPCC's A1B) is the most likely in 2030. However, the range of possibilities expands further into an uncertain future that will be determined by emissions not yet released. To encompass the range of possibilities in 2050 and 2070 the focus will be on the low (IPCC's B1) and high (IPCC's A1F1) emissions scenarios, although mid range is presented as well. These low, mid and high emission scenarios are in comparison to a baseline of the present average, accounting for climate model consistency (1980-1999).

It should be kept in mind that there are strong indications that a high emissions scenario may be the most likely in the future. The Director of the Fenner School of Environment and Society at the Australia National University indicates such in the following quote:

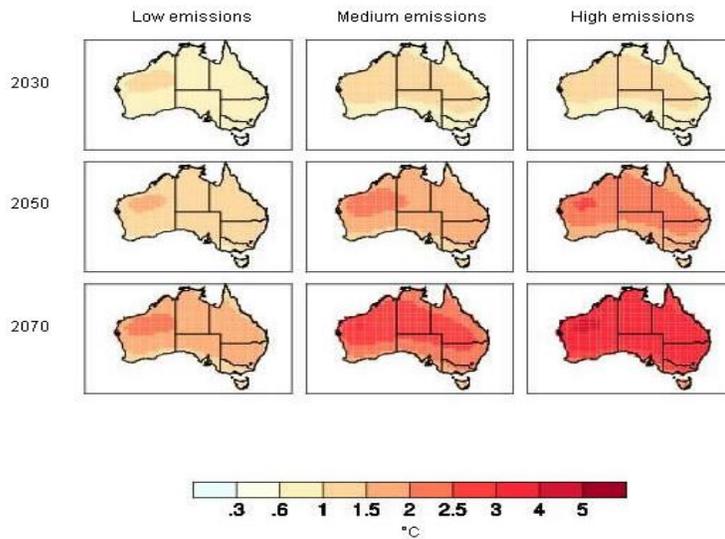
‘Both observed temperature and sea-level rise are tracking at or near the top of the envelope of model projections. With regard to sea level, the current trajectory, should it be maintained, would lead to a sea-level rise of nearly one meter by 2100, well above the median of the AR4 (IPCC Fourth Assessment Report) projections and slightly above its upper projection.’ (Steffen, 2007: 2).

This analysis is reiterated by the United States of America National Academy of Sciences, who point out that current greenhouse gas emissions are actually exceeding what has been projected by the IPCC estimates (Raupauch et al., 2007; Canadell et al., 2007). What this indicates is that although climate models do not provide absolute certainty of outcomes, there may be an even greater likelihood of the more severe changes associated with high emissions scenarios in the future.

### ***Overall trends in Australia***

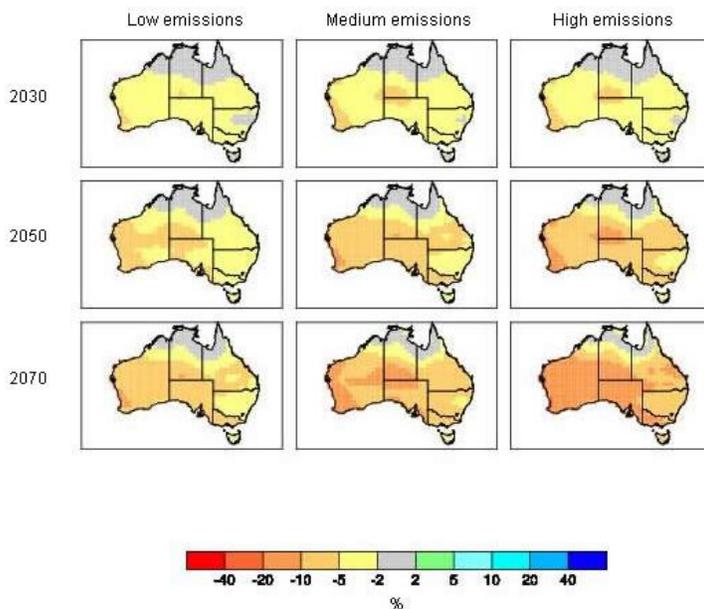
While there is significant regional variation, Australia wide there has been an overall increase of average temperature by 0.9°C from 1950 to 2006, and this is expected to increase in the future (CSIRO and BOM 2007b). Relative to 1990, it is estimated that Australia's average annual temperature will have increased by 1°C under a mid range scenario by 2030, with a range of uncertainty between 0.6°C to 1.5°C. Further into the future, a low emissions scenario will put the average temperature increase in Australia at about 1.5°C in 2050 and 1.8°C in 2070, while under high emissions the temperature increase will be about 2.5°C in 2050 and 3.4°C in 2070 (CSIRO and BOM, 2007a).

**Figure 3:** National annual temperature change 50<sup>th</sup> Percentile (CSIRO and BOM 2007a)



In regards to rainfall there have been increases in north-west and central Australia, but substantial declines in eastern and southwestern Australia over the last sixty years. By 2030, it is expected that the annual average rainfall will be between -10% to +5% in the north and -10% to 0% in the south. By 2070 the low emissions scenario could result in -20% to +10% in the center, east and north and -20% to 0 in the south. The 2070 high emissions case could lead to -30% to +20% in the center, east and north, and -30% to +5% in the south (CSIRO and BoM, 2007a).

**Figure 4:** National annual rainfall change 50<sup>th</sup> percentile. (CSIRO and BOM, 2007a)

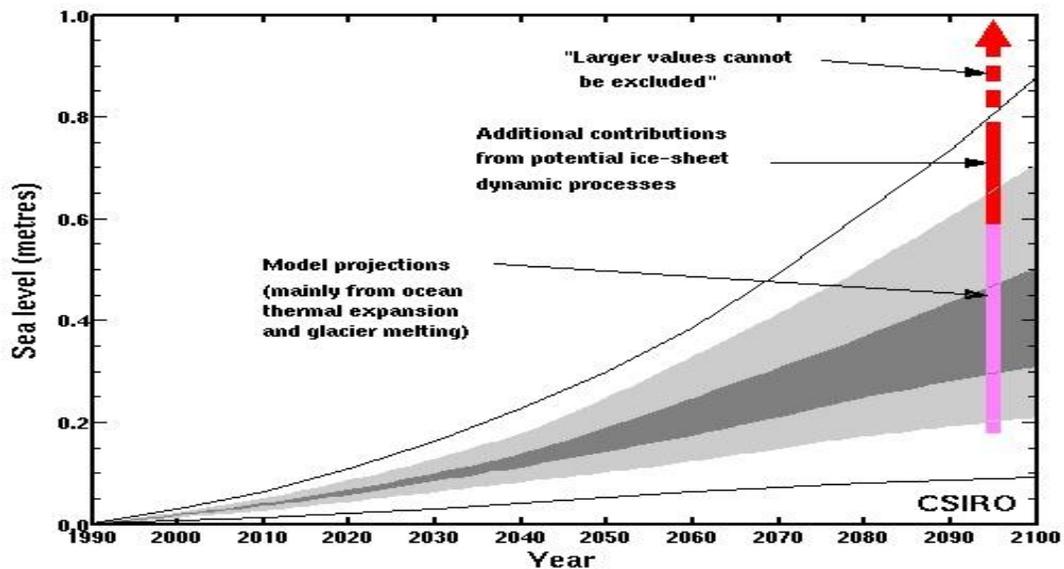


Other impacts include up to 20% more drought months by 2030 and 40% by 2070 Australia wide, with a concurrent increase in the length of the fire season. Severe weather,

including cyclones and hail storms, is also predicted to increase in intensity along with storm surges and higher sea levels (CSIRO and BoM, 2007b). An interesting projection over the next fifty years is that the occurrence of tropical cyclones will possibly decrease by 50% and the duration may decrease by about 0.3 days (Abbs, 2009). However, the tropical cyclones that do occur will likely be more intense, exhibiting deeper pressures and a greater proportion exhibiting maximum wind speeds (exceeding 25m/s) in the 2070 models than occurred in 1980 or the 2030 models (Abbs, 2009).

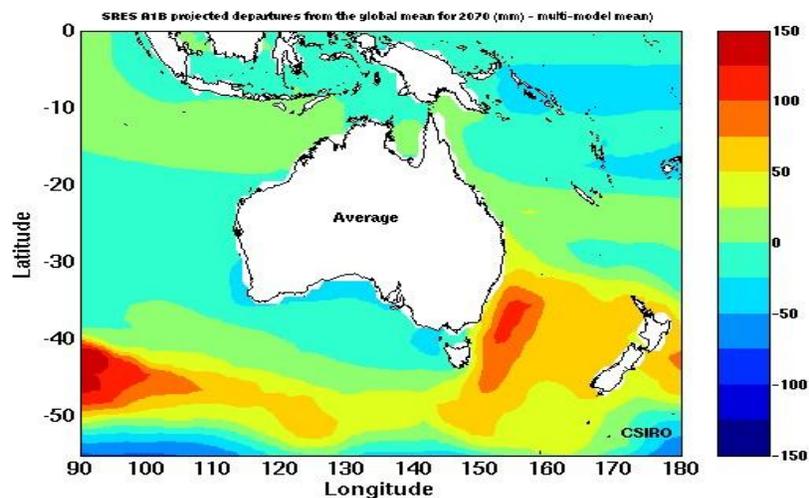
Sea level rise is projected to reach up to a meter by 2100, with regional variation that in most cases will add to the level of increase (CSIRO, 2110a). The figures presented below illustrate first the projected global sea level rise up to 2100, followed by a diagram of projected departures from the mean global sea level rise in 2070. This second map illustrates that parts of Australia will likely experience higher than average sea levels, particularly the south-east, as well as the entire north and north-east coastline discussed in this report.

**Figure 5:** Projected global sea-level rise for the 21<sup>st</sup> century. (CSIRO, 2010a).



The graph above illustrates the projected range of global averaged sea-level rise from the IPCC 2001 Assessment Report (Church et al., 2001) by the lines and shading. The central dark shading is an average of models for the range of SRES greenhouse gas emission scenarios. The light shading is the range for all models and all SRES scenarios and the outer bold lines include an allowance for land-ice uncertainty (CSIRO, 2010a).

**Figure 6:** SRES A1B Projected Sea level Departures from the Global Mean (mm) 2070 (CSIRO, 2010b).



Overall, climate change projections – including changes in rainfall, temperature, carbon dioxide and other climatic variables – if realized, are likely to affect forage and animal production, and ecosystem functioning. The major known uncertainties in quantifying climate change impacts on ecosystems are: (i) carbon dioxide effects on forage production, quality, nutrient cycling and competition between life forms (e.g. grass, shrubs and trees); and (ii) the future role of woody plants including effects of fire, climatic extremes and management for carbon storage (McKeon et al, 2009). Despite inherent uncertainties in the projections of impacts, it is expected that climate change will result in significant changes to environmental, institutional and social systems across Australia.

### ***Overview of Environmental Impacts across North***

Northern Australia is likely to experience hotter temperatures, more intense rainfall and more intense cyclone events, and rising sea level due to climate change. As a result, coastal areas will be at greater risk of erosion and salt water inundation, while inland areas are likely to experience greater extremes in temperature with more droughts and flooding, dust storms and bushfires (CSIRO, 2009a; Green 2006). By 2030, northern Australia will likely see increased temperatures and although some areas will receive more rainfall, there will be less water available overall, with ecosystems under increased pressure (Hyder Consulting, 2008). Cyclones and other severe weather will likely increase in intensity, if not frequency, and this in conjunction with rising sea levels will threaten low lying areas such as Kakadu National Park and sea ports in the Kimberley and Cape York regions (Northern Australia Land and Water Taskforce, 2009).

The table below provides an overview of the climate change impacts in Northern Australia related to changes in temperature, rainfall, evapotranspiration and days of

+35°C. Although most climate change impacts across the north are largely similar amongst the three regions, some slight variations can be appreciated, particularly within the Kimberley. The north of Western Australia is more likely to experience greater variability in future rainfall, evapotranspiration and hot days than the eastern regions of north Australia. At the same time, northern Queensland may not experience the same level of temperature increases as the western regions until after 2050 (high). This data is described in more detail in the individual regional projections provided in the next section.

**Table 5:** Climate Change impacts across Northern Australia (2030, 2050 and 2070) (Annual, 50<sup>th</sup> percentile) (CSIRO and BOM 2007a; Hennessy et al 2010, in review).

Changes relative to 1990 in:	Western Australia (Northern Region)	Northern Territory (Northern Region)	Queensland (Northern Region)
<b>Temperature °C</b>			
2030 (mid)	1.5	0.6 to 1.5	1
2050 (low)	1 to 1.5	1 to 1.5	0.6 to 1.5
2050 (high)	2 to 2.5	1.5 to 2	1.5 to 2.5
2070 (low)	1.5 to 2.5	1 to 2	1 to 2
2070 (high)	2.5 to 4	2.5 to 4	2.5 to 4
<b>Rainfall (%)</b>			
2030 (mid)	-2 to +2	-2 to +2	-2 to +2
2050 (low)	-5 to +2	-2 to +2	-5 to +2
2050 (high)	-10 to +2	-5 to +2	-5 to +2
2070 (low)	-10 to +2	-5 to +2	-5 to +2
2070 (high)	-20 to +2	-10 to +2	-10 to +2
<b>Evapotranspiration (%)</b>			
2030 (mid)	2 to 4	2 to 4	2 to 4
2050 (low)	4 to 8	2 to 4	2 to 4
2050 (high)	4 to 8	4 to 8	4 to 8
2070 (low)	4 to 8	4 to 8	4 to 8
2070 (high)	8 to 12	8 to 12	8 to 12
<b>Days +35 °C</b>			
<b>Current</b>	(Broome) 38	(Darwin) 11	(Cairns) 3.8
2030 (mid)	83	37	6
2050 (low)	93	49	7
2050 (high)	127	98	13
2070 (low)	110	74	9
2070 (high)	193	188	35

In northern Australia water availability may not seem to be a critical issue because of current high levels of rainfall and predictions of minimal change for 2030. Although highly variable, the average annual rainfall in Northern Australia is 1 077 000 GL, most of which falls during the wet season, between November and April (CSIRO, 2009a).

However, the area is described as ‘water-limited’ despite the large amount of rainfall because of the high rate of evaporation and plant transpiration (evapotranspiration) during most of the year (CSIRO, 2009a). Another factor negatively impacting water availability is a lack of suitable surface water storage options, and significant longer term impacts from groundwater extraction, although current demands pose little threat. Overall, the area is expected to experience similar levels of rainfall in 2030 to the historical average, and slightly higher levels of evapotranspiration (CSIRO, 2009a). It is expected that rainfall intensity will likely increase, along with severe weather events, as the air will be both warmer and more moisture laden (McKeon et al, 2009). However, it is difficult to project future rainfall patterns because unlike temperature, which directly correlates to greenhouse gas concentrations, rainfall depends on general atmospheric circulation, which often leads to discrepancies between models (CSIRO and BOM, 2007b). It should also be kept in mind that climate models become less predictive at smaller scales and while they can indicate general trends, future regional changes are less certain.

Northern Australia encompasses nineteen defined bioregions and a wide range of habitats, including the world’s largest intact tropical savannah and a vast network of tropical rivers and wetlands (ATRG, 2004). Other ecosystems in the North include monsoon and rain forests, coral reefs, mangrove systems, heathlands and mound springs (Hyder Consulting, 2008). Hyder Consulting (2008) provide an overview of the impact of climate change on northern ecosystems over the next twenty years. They argue that coastal low lying wetlands are at medium to high risk due to climate impacts such as rising sea levels, and increased severe weather and sea water inundation, as well as expanding agricultural, urban and industrial infrastructure. Coral reefs are also at high to medium risk, as are tropical rainforests and tropical savannahs and small island environments. Tropical rivers are said to be at low to medium risk chiefly because of rainfall variability. Biodiversity across northern Australia is expected to be reduced significantly by 2020, particularly because of impacts to the Great Barrier Reef, Kakadu wetlands and Queensland’s tropical north. In each case, it is argued that the physical impacts of climate change can be seriously exacerbated by poor planning that weakens rather than strengthens ecosystem responses (Hyder Consulting, 2008).

### ***Overview of Socio-Economic Impacts across North***

Climate change will most likely impact each of the dominant industries across the north, namely agriculture, tourism and mining, as well as human infrastructure, health and culture. However, the extent of negative consequences can be determined by both public and institutional adaptive strategies (Hyder Consulting, 2008). Agriculture and pastoralism will experience largely negative impacts from more intense climatic conditions jeopardizing growing conditions and territory (McKeon et al, 2009; Gunaskera et al, 2007; Department of Climate Change and Energy Efficiency, 2010). The mining industry may experience declines in certain areas, as global demand for resources such as coal and aluminum decreases because of responses to climate change (Queensland Government, 2009). However, as with agriculture, climate change could deliver new opportunities in the mining sector, with demands for carbon neutral energy sources such

as uranium expected to grow (Queensland Government, 2009). The tourism sector across the north is expected to be negatively impacted by climate changes that alter or destroy important natural attractions such as the Great Barrier Reef and wetlands and rainforests (Queensland Government, 2009; Department of Climate Change and Energy Efficiency, 2010). Rising temperatures and numbers of extremely hot days could also make the north a less attractive tourist destination.

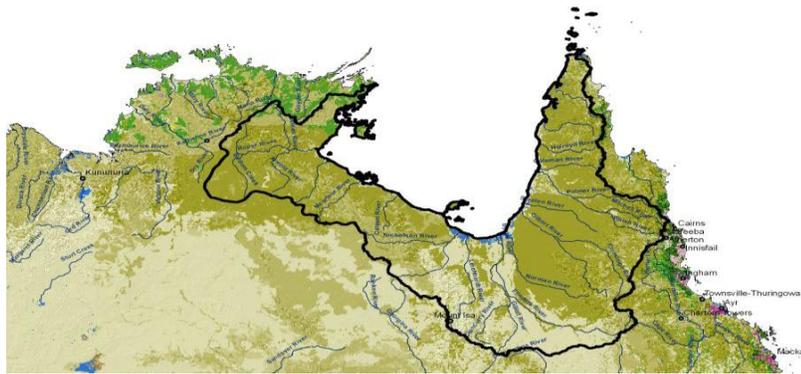
For residents of northern Australia, climate change will likely make living more difficult through negative impacts on infrastructure, human health and cultural life. Increased erosion, salt water inundation and extreme weather events will put transportation, residential and commercial infrastructure at risk. Potable water supply could be increasingly vulnerable without adequate adaptation, as ground and surface water storages are depleted, especially in remote areas (CSIRO, 2009a; Hyder Consulting, 2008). Health problems such as heat related illnesses and deaths, and food and water borne diseases may increase along with rising temperatures (Green, 2006). Mosquito born diseases are also likely to increase in frequency and area. Remote communities in particular, many of them aboriginal, will be at elevated risk of health impacts (Green, 2006). At the same time, aboriginal social and cultural vitality could be jeopardized by the destruction of ecosystems central to cultural continuity and mental wellbeing (Green, 2006). Overall, the projected increased intensity of heat and extreme weather in the north will likely make life more difficult for the majority, although many of the socio-economic impacts highlighted here can be moderated by proactive planning.

### 3. Projected Regional Impacts

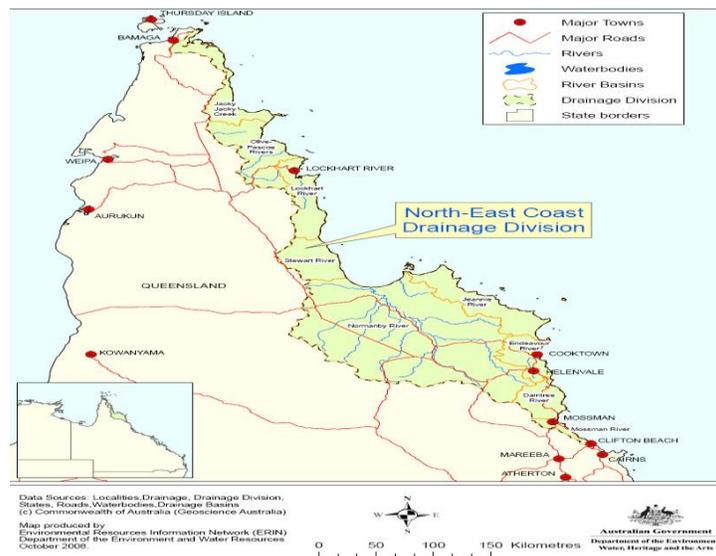
#### 3.1 Queensland Overview: The Gulf of Carpentaria and the Northern North East Coast Drainage Divisions

Northern Queensland contains two major drainage divisions, the Gulf of Carpentaria (647 000 km) and the Northern North East Coast (50 000 km) (see Figures 7 and 8). TRaCK estimates of the population in Queensland’s northern drainage divisions are 132 248 total and 27 526 Indigenous (Carson et al, 2009). Eastern regions of the Gulf of Carpentaria overlap into the Northern Territory, and environmental and socio-economic information is presented separately for the Northern Territory due to a lack of regionally specific data.

**Figure 7:** Gulf of Carpentaria (CSIRO, BOM and BRS, 2010)



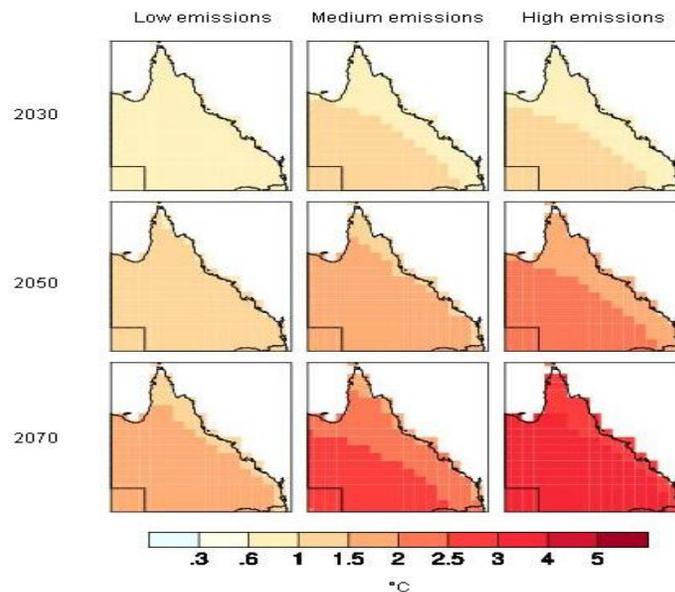
**Figure 8:** Northern North East Coast Drainage Division (ERIN, 2008)



### 3.1.1 Environmental Impacts

Overall, the average annual temperature in Queensland has been increasing since 1910, with an annual rate of increase of  $0.07^{\circ}\text{C}$  in the far north. Four of the seven hottest years recorded have happened since 2002 and since 1950 there have been more days over  $35^{\circ}\text{C}$  and fewer nights below  $5^{\circ}\text{C}$  than prior to this time (CSIRO, 2007b). By 2030 it is expected that under a mid-range emissions scenario the annual average temperature of Queensland will increase by about  $1^{\circ}\text{C}$  relative to the baseline average of the 1990's. Regional differences may become more marked in the future, so projections for temperature, rainfall and evaporation will be given for the northern regions of Queensland relevant to this report. In 2050 the temperature is expected to increase by  $0.6^{\circ}\text{C}$  to  $1.5^{\circ}\text{C}$  for low and  $1.5^{\circ}\text{C}$  to  $2.5^{\circ}\text{C}$  for high emissions scenarios. Further increases are expected by 2070, with projected changes of  $1^{\circ}\text{C}$  to  $2^{\circ}\text{C}$  for low and  $2.5^{\circ}\text{C}$  to  $4^{\circ}\text{C}$  for high emissions scenarios (CSIRO, 2007a).

**Figure 9:** Queensland temperature changes ( $^{\circ}\text{C}$ ), 2030, 2050, and 2070 (annual, 50<sup>th</sup> percentile) (CSIRO and BoM, 2007a).



In exploring more precise regional variations of climate change impacts across the North, Green (2006) used the OZCLIM climate scenario generator and averaged the results from an array of climate models and emissions scenarios to produce central estimates for 2050. Her results will be presented here as well to illustrate the more localized potential impacts of climate change that are not illustrated by the general scenarios of CSIRO and BOM (2007a). In the Gulf of Carpentaria she estimated an increase of  $1.3^{\circ}\text{C}$  to  $2^{\circ}\text{C}$ , and in Cape York and the Torres Strait Islands  $1.3^{\circ}\text{C}$  to  $1.8^{\circ}\text{C}$  by 2050.

There are expected to be increased numbers of  $+35^{\circ}\text{C}$  days in Queensland. Presently, Cairns receives 3.8 days per year, but this is expected to increase to about 6 by 2030

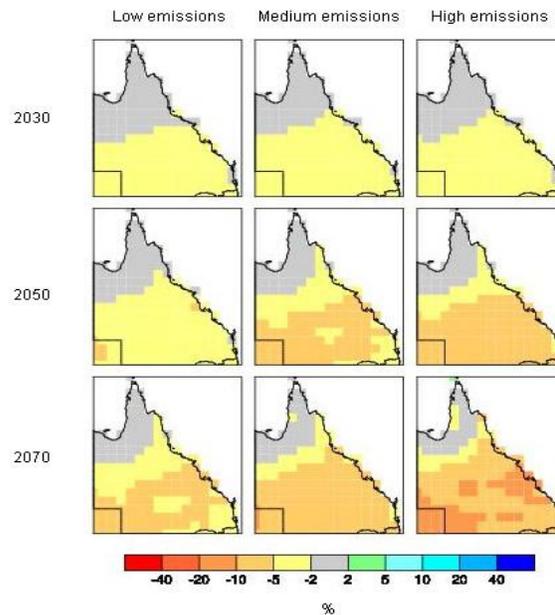
(mid-range), and 9 (low-range) or 35 (high-range) by 2070 (Hennessy et al., 2010 in review) (see table 6).

**Table 6:** Number of +35°C Days per Year in Cairns, 2030, 2050 and 2070. (Sourced from Hennessy et al, 2010, in review)

Cairns	Low (B1)	Mid (A1B)	High (A1F1)
(3.47)			
2030	-	<b>6</b>	-
2050	7	10	13
2070	<b>9</b>	18	<b>35</b>

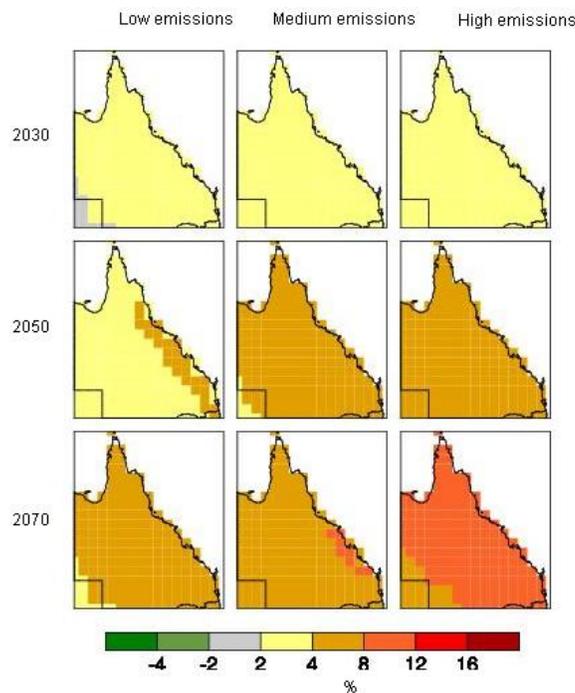
Rainfall patterns have changed since the 1970's, with rainfall more likely to occur less often today and in extreme weather events (CSIRO and BOM, 2007b). McKeon et al, (2009) estimate that since 1970 there have been declines of 50 mm per decade in north-eastern Queensland. In the future, while considerable uncertainty exists, the mid-range estimate is that northern Queensland will see a -5% to +2% change in rainfall by 2030. 2050 estimates under a low emissions scenario are basically the same as those for 2030. The 2050 estimates under the high emissions scenario increase the chances of less rainfall to between -10% to +2%. Again, the low emissions 2070 scenario is very similar to the 2050 high emissions scenario, while 2070 high emissions projections show a larger region is more likely to have rainfall decreases, around the -10% mark, and possibly even less in southern areas. In the far north it seems likely that there could be minimal rainfall change regardless of emission scenario or year.

**Figure 10:** Queensland Rainfall Change (%), 2030, 2050, and 2070 (annual, 50<sup>th</sup> percentile) (CSIRO and BOM, 2007a).



Green (2006) estimates that precipitation could change by +/- 4% by 2050 in the Gulf, and +/- 2% in Cape York. Although rainfall patterns may not change a great deal, evapotranspiration is predicted to increase and this will contribute to an increase in aridity and drought, regardless of rainfall levels (CSIRO, 2009a; CSIRO and BoM, 2007b). The figure below demonstrates that percentage increases in evapotranspiration will exceed those of rainfall decreases by a great deal. While there is only about a 2% to 4% projected increase for 2030 (mid) and 2050 (low), the 2050 (high) and 2070 (low) scenarios both have evapotranspiration increases up to between 4% to 8%, and 8% to 12% in the 2070 (high) scenario.

**Figure 11:** Queensland potential evapotranspiration 2030, 2050 and 2070 (annual, 50<sup>th</sup> percentile) (CSIRO and BOM 2007a).



Studies on projected outcomes in Queensland reflect the difficulty of projecting future tropical cyclone frequency and intensity. Walsh et al (2004) estimated an increase of severe tropical cyclones of 56% by 2050, while Green (2006) predicts that cyclone risk will actually be low for coastal areas in the Gulf and Cape York in the future (2050). Another possibility is a decrease in the frequency of total tropical cyclones, but an increase in the number of those that are more severe (Abbs, 2009). There is also about a four percent increase in the chance of extreme rainfall events across northern Queensland (CSIRO and BOM, 2007b).

There is a possibility that by 2070 sea level rise on the East Coast of Queensland and the Gulf may exceed by 5 cm the IPCC's projected 79 cm, for a total rise of 84 cm (Office of Climate Change, 2010; CSIRO and BOM, 2007b). This could mean that the Torres

Straight Islands and coastal communities see increasing salt water intrusion and heightened risks from weather events. With the expected increase in sea level and intensity of weather events there is also a significant risk that storm surge area will expand (Office of Climate Change, 2010). Green (2006) projects that by 2050 areas around the entire southern Gulf shore, including Borrooloola, Mornington Island, Roper River area and Groote Island may be exposed to salt water inundation and erosion. In Cape York, she suggests the Mitchell River and coastal areas south of there, including the nearby settlement of Kowanyama, and the Torres Straight Islands will also be at risk of inundation.

It is likely that water flow will be altered by the impacts of climate change across Northern Queensland. The most well known ecological assets in Northern Queensland include the world heritage listed Great Barrier Reef and Wet Tropics, both of which face serious ecological destruction as a result of climate change (Hyder Consulting, 2008). The tropical forests of Queensland's north are particularly vulnerable to alterations of the climate, and potential for ecological change in the future is high (Hilbert et al, 2001). The wealth of unique and evolutionary significant species in the wet tropics are highly adapted to the specific biogeography of Northern Queensland, and are also highly vulnerable to changes in this climate (Williams, 2006). Bioclimatic modelling shows the potential for catastrophic species extinction as a result of climate change (Williams et al., 2003), with a potential 74% of rainforest birds under threat of extinction over the next century (Shoo, 2005). Increased temperature and reduced precipitation are expected to result in increased fire and drought, and tropical rainforests are at elevated risk due to sea level rise, severe weather and reductions in cloud cover (Williams, 2006).

The Great Barrier Reef is currently considered one of the world's healthiest coral reefs (WWF, 2004). However, predictions of sea and air temperature warming and increased cyclonic activity lead scientists to predict the eventual catastrophic destruction of the reef and related species. It is estimated in the Fourth Assessment Report that the Reef could be bleached by 60% by 2020, 97% by 2050 and totally destroyed by 2080 (IPCC, 2007b). Increased sea levels could help some marine species expand their territories, but will likely smother others (Wilkinson, 1996). In general, a warming climate tends to alter species distributions as flora and fauna shift towards high latitudes, and this trend is expected to accelerate (Root et al, 2003).

### **3.1.2 Socio-Economic Impacts**

Overall, Queensland is the Australian state most at risk of economic loss due to unmitigated climate change, with losses predicted to increase at a faster rate during the latter half of the century (Queensland Government, 2009). However, this decline relative to other states is largely due to Queensland's current status of rapid, emissions intensive growth, and over the long term it is expected that Queensland will actually have higher long term annual economic growth than elsewhere in Australia (Commonwealth of Australia, 2008). In agriculture, Queensland is predicted to suffer large reductions in agricultural productivity and exports due to climate change (Gunasekera et al, 2007). While rainfall may not decline significantly, the likely increases in evapotranspiration

and soil erosion, as well as changes in plant productivity, pests, diseases and weeds and general growing conditions will impact the viability of agricultural endeavours. The picture is not all negative as there could be increased opportunities with the warming climate to cultivate plants that are sensitive to frost (Queensland Government, 2009).

There could be negative impacts to pastoralism as pasture, feed quality and animal reproduction is reduced due to the climate impacts discussed. McKeon et al, (2009) conducted simulations of forage production to determine how livestock carrying capacity (LLC) is impacted by temperature, rainfall and carbon dioxide changes. One of their findings was that a 3°C temperature rise would probably reduce forage production in the majority of Australian rangelands by -21%, however, they also suggested a carbon dioxide increase to 650 ppm could result in +26% forage production. In light of these conflicting messages, they offer that “the large magnitude of these opposing effects emphasizes the importance of the uncertainties in quantifying the impacts of these components of climate change” (McKeon et al, 2009: 22). They go on to conclude that despite variations in predicted impacts and modeling, the likelihood is that LLC across Australia will be reduced, with important implication for the economy and employment.

While certain industries may likely contract due to impacts of global mitigation such as carbon pricing, other industries are likely to grow, such as renewable energy and forestry (Queensland Government, 2009). It is also likely that increased intensity and frequency of extreme weather events will negatively impact fisheries (Queensland Government, 2009).

Tourism plays a significant role in the Queensland economy and natural resources like the Great Barrier Reef are very sensitive to climate change impacts. It was estimated that the Great Barrier Reef generated \$4.9 billion and full time employment for 59 000 individuals in 2004-2005 (Access Economics, 2005). It is expected that declining quality in environments like the northern tropics and Great Barrier Reef will lead to decreased tourist numbers and dollars (Queensland Government, 2009).

The Office of Climate Change (2010) argues that Queensland’s infrastructure is at great risk, not only because of the expanding coastal population, but also because local level uncertainties in climate modelling stem progressive adaptation. They indicate that the design of transport, residential and commercial infrastructure should incorporate potential climate change risks through updated building standards and codes. Of special consideration are the remote indigenous communities, who will be at greater risk of being cut off due to extreme weather and flooding. In Cape York, some communities are already having difficulty as their airstrips are under threat from beach erosion (Queensland Government, 2009).

The Queensland Government (2009) highlights a range of social impacts briefly described here, also, for a detailed description on the health impacts of climate change see Green (2006). Global warming will result in increases of direct loss of life and injury due to temperature rise and extreme weather events across Queensland. Dengue fever has already been on the increase for the past decade, and a larger territory compounded by

increased population will likely lead to a greater range of infections. It is predicted that under a high emissions scenario the Australian incidences of Dengue fever could increase from 310 000 in 2000 to 540 000 by 2030. It is also likely that Ross River virus and malaria will increase in the tropical north. There will also be greater risk of food and water borne diseases due to increased temperatures, which could be especially harmful in remote indigenous communities.

Social disruption and displacement is likely, especially for low income and disadvantaged groups, and those in regions that are dependant on agriculture and tourism, both of which are highly vulnerable to a climate changes. Overall, there will be a greater reliance on health services for rural communities struggling with decline and experiencing associated psychological and mental health problems. Aboriginal communities especially are at risk of increased physical hardships, as well as potential cultural disruption brought about by the destruction or alteration of ecosystems central to traditional culture (Garnaut, 2008).

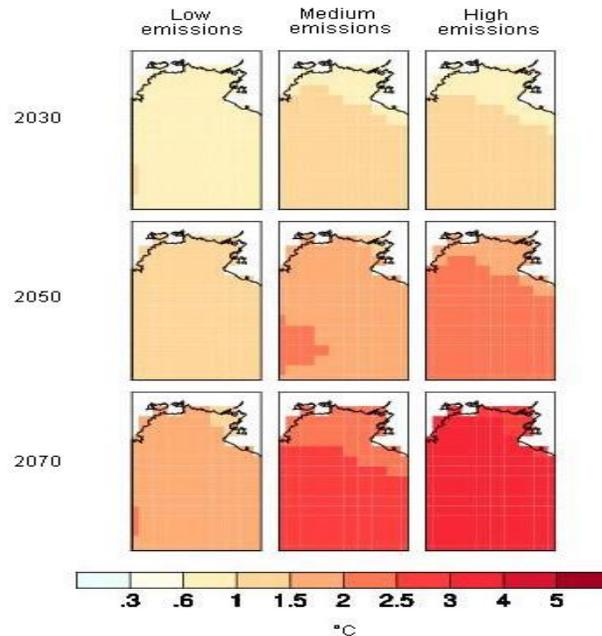
### ***3.2. Northern Territory Overview: Top End (Katherine to Darwin)***

Both the Gulf of Carpentaria and Timor Sea Drainage Divisions extend into the Northern Territory, as highlighted by Figure 1. TRaCK estimates the population encompassed by the northern drainage divisions of the Northern Territory to be 149 587 total and 39 498 Indigenous people (Carson et al, 2009).

#### **3.2.1 Environmental Impacts**

CSIRO and BOM (2007a) data show that the NT's average annual temperature has been increasing since 1960, and is now 0.6°C greater than in the past. Relative to the 1990's baseline scenario, it is expected that by 2030 (mid) the average annual temperature will increase by 0.6°C to 1.5°C. Regional differences may become more marked in the future, so projections for temperature, rainfall and evaporation will be given for the northern regions of the Northern Territory relevant to this report. In 2050 the temperature is expected to increase by between 1°C and 1.5°C for low and between 1.5°C to 2°C for high emissions scenarios. Further increases are expected by 2070, when low emissions see an increase of between 1°C and 2°C and high emissions scenarios correlate with projected temperature increases of between 2.5°C and 4°C. Green (2006) estimates that by 2050 the temperature in Kakadu and Arnhem Land will increase by between 1.9°C to 2.2°C.

**Figure 12:** NT temperature changes (°C), 2030, 2050, and 2070 (annual, 50<sup>th</sup> percentile) (CSIRO and BOM, 2007a).



The frequency of +35°C is expected to rise considerably in the Northern NT, as are episodes of heat spells of three or more days in a row with +35°C temperatures. Darwin’s current average of 11 hot days per year could rise to about 37 (mid) by 2030, and 74 (low) and 188 (high) by 2070 (Hennessy et al., 2010, in review).

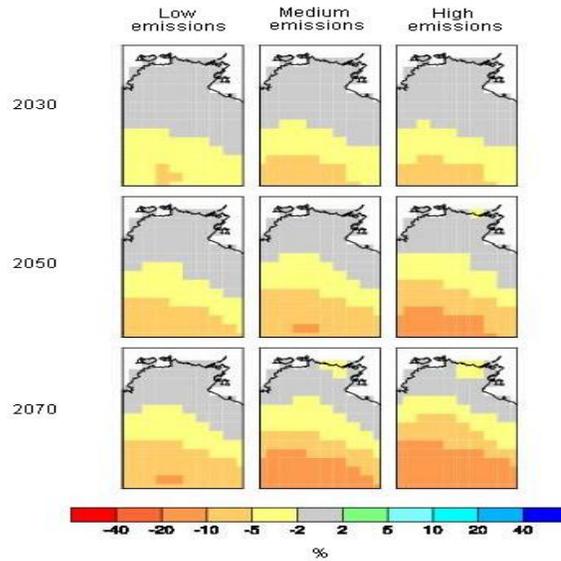
**Table 7:** Number of +35 °C Days per Year in Darwin, 2030, 2050 and 2070 (Hennessy et al., 2010, in review).

Darwin (10.97)	Low (B1)	Mid (A1B)	High (A1F1)
2030	-	<b>37</b>	-
2050	49	77	98
2070	<b>74</b>	125	<b>188</b>

As with most of Australia, it is predicted that the intensity and frequency of droughts will increase in the future. Again, rainfall is difficult to predict, but models indicate that it is likely that most areas will experience less rainfall, although episodes of heavy rain may increase. The scenarios mapped below indicate that there will likely be little change in amount of rainfall in the Northern NT regardless of year or emissions, although declines of up to 5% could occur in the southern TRaCK region under high emissions scenarios in 2050 and 2070. There is also a likelihood that decreases of between -5% to -2% could occur in the coastal area of Arnhem Land under a high emissions scenario in both 2050

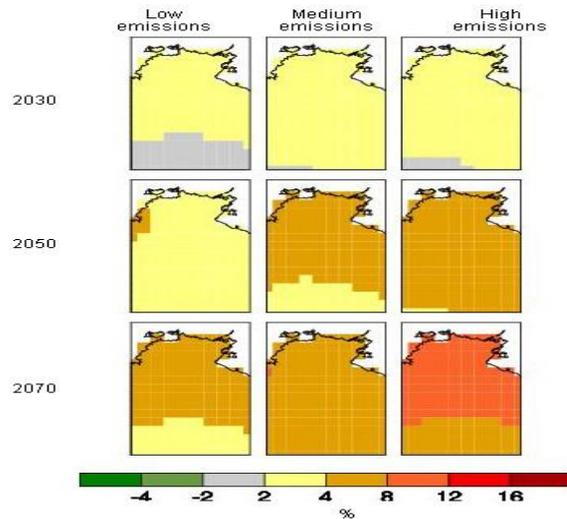
and 2070. Green (2006) estimates that by 2050 the Kakadu and Arnhem Land region will experience +/- 4% precipitation change.

**Figure 13:** Northern Territory Rainfall Change (%), 2030, 2050, and 2070. (annual, 50<sup>th</sup> percentile) (CSIRO and BOM, 2007a).



The next figure demonstrates that increases in evapotranspiration will exceed those of rainfall decreases by a great deal. Similar to northern Queensland, while there is only about a 2% to 4% projected increase for 2030 (mid) and 2050 (low), the 2050 (high) and 2070 (low) scenarios both have evapotranspiration increases up to between 4% to 8%, and 8% to 12% in the 2070 (high) scenario.

**Figure 14:** Northern Territory Potential evapotranspiration 2030, 2050 and 2070 (annual, 50<sup>th</sup> percentile) (CSIRO and BOM 2007a).



Cyclonic activity will likely intensify in the future, although as mentioned previously, the frequency may decrease (Abbs, 2009). The combination of more intense cyclones and a rising sea level indicates that storm surges will be more powerful and destructive. As well, inland flooding may also increase as a result of heavier rainfall and elevated sea levels (Green, 2006). Green (2006) estimates that Melville Island will be at an above average risk of exposure to cyclonic activity. Green (2006) provides a list of locations likely to be exposed to salt water inundation and erosion by 2050 in the Northern Territory: Finiss River, Daly River, Hyland Bay, Keyling Inlet, Victoria River, Adelaide River, Chambers Bay, West Alligator River, South Alligator River, East Alligator River, Arafura wetlands, Maningrida, Milingimbi, Glyde River, Buckingham Bay, and Arnhem Bay.

Over the past fifty years the world heritage listed Kakadu wetlands have been subjected to increased saltwater intrusion resulting in a variety of adverse effects, including the destruction of freshwater and vegetation species as well crocodile breeding grounds (Winn et al, 2006). Although not all species have been affected, research indicates that a gradual decline in mammal species has been occurring, and that this decline may be because of reduced rainfall and groundwater levels (Braithwaite and Muller, 1997). Projected temperature increases could seriously impact species with temperature sex determination, like the pig nosed turtle, and salt and fresh water crocodiles (Webb et al, 1986). Currently the Kakadu coastal wetlands are only 0.2-1.2 m above sea level (Eliot et al, 1999). It has been projected that a sea level rise of 30 cm could displace 80% of freshwater wetlands in the North, and this level is well within the IPCC (2007) estimate of 0.18 to 0.59 m by 2100 (Hare, 2003). Further, an increase in average temperatures of 2°C to 3°C could lead to the loss of 80 per cent of freshwater wetlands in Kakadu (Department of Climate Change and Energy Efficiency, 2010).

### **3.2.2 Socio-Economic Impacts**

Erosion and salt-water inundation are two significant risk factors for human settlements in the NT. The Department of Climate Change (2009, section 1.5.8) provides a thorough assessment of current and future impacts of climate risks to Australia's coasts, which will inform the following paragraph. Although infrastructure in the Northern Territory has progressed significantly since Cyclone Tracy in 1974, there are concerns that the current infrastructure is at serious risk from future climate change. Currently, storm shelters are built to withstand a category 4 cyclone; however, the likelihood of more intense cyclone activity is a consistent projection in climate models. Another issue is that existing shelters are unable to accommodate the majority of the population, which has been rapidly expanding since 2003. It is estimated that about 180 residential buildings in the NT, most in Darwin and Litchfield, would be at risk from inundation from a sea level rise of 1.1 m. Further, there are 190 buildings within 110 m of the coastline that are currently at risk from erosion, most in Darwin. Erosion is an ongoing concern due to the relatively high distribution of "soft" low profile coastal rock (15%) along the NT's coast, which actively recedes with sea-level rise. Storm surges represent another threat to infrastructure, as the railway and many minor roads would be impassable with only a moderate increase in storm surge.

The image below shows how much of Darwin could be submerged by a 1.1 m sea level rise.

**Figure 15:** Sea level rise projections in Darwin (Department of Climate Change, 2009: 114).

Darwin (2009)



Darwin +1.1m sea level



Population growth in the NT has been very rapid over the past decade, averaging 1.9% per year between 2003 and 2008 for a total of 9.9% during this time. Darwin has grown faster than any other capital city in Australia, at a rate of 12.3% (Department of Climate Change, 2009). A recent mining and resources boom led to a 32.4% increase in Gross State Product from 2003/4 to 2005/6 (ABS, 2007). The NT is characterized as being a small, resource based (agriculture and mining) economy with a substantial proportion of employment generated from service industries associated with tourism (Northern Territory Government, 2010).

Agriculture in the NT will be threatened by potential ecosystem changes altering growing conditions of crops and viability of pastoralism. Currently the NT exports \$218 million worth of cattle per year, but this amount is projected to decrease by 19.5% in 2030 and 33.2% by 2070 due to changing conditions (Department of Climate Change and Energy Efficiency, 2010). Tourism is also an important contributor to the economy and jobs, with 1.38 million annual visitors in 2005-6 spending over \$1.5 billion (Department of Climate Change and Energy Efficiency, 2010). Negative impacts to popular destinations like Kakadu National Park would be detrimental for entire communities relying on the tourism industry.

Increased temperatures, and the frequency of days over 35°C, are especially likely in the territory. As noted earlier, Darwin could face up to 188 +35°C days in 2070 (CSIRO and BOM, 2007b). Temperatures such as these pose a real risk for heat exhaustion, heat stroke and death, especially for the elderly and poor physical conditioning (Green, 2006). It is also possible that bacterial diarrhea may increase along with a hotter climate (McMicheal et al, 2003). Mosquito born diseases have not yet been a large concern in the territory, but

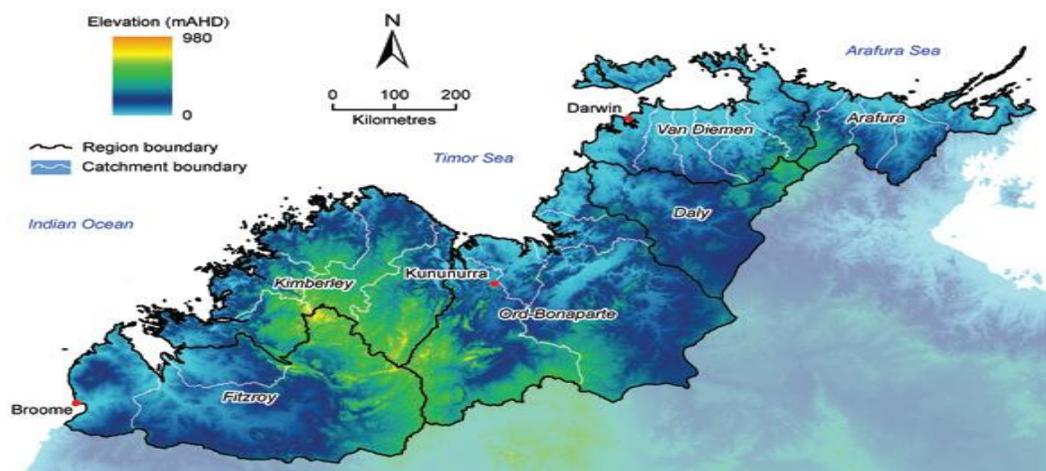
climate projections could see them spread east and south along the coasts from Queensland's far north (Green, 2006).

Heavier rainfall is associated with increases in Murray Valley encephalitis (MVE) in northern Australia, particularly Alice Springs and Tennant Creek (Whelan et al, 2003). Melioidosis and infectious enteric diseases causing diarrhea in children are also more likely to increase in the north under wetter conditions (Green, 2006). Green (2006) describes that extreme events themselves are likely to bring about more injuries and deaths and reduce the effectiveness of emergency response. Another issue relevant to the Indigenous population especially is that ecosystem change will likely impact food supply, as flora and fauna migrate to new areas or disappear entirely. Green (2006) argues that “when considering the likely health impacts from climate change on Indigenous Australians living in remote communities it is crucial to explicitly address the interconnections between the health of ‘country’, culture and mental and physical well-being” (3). Many remote communities are dependant physically and culturally on their local food sources, and disruptions could lead to malnutrition, as well as mental health problems.

### **3.3 Western Australia Overview, East and West Kimberley.**

The Timor Sea drainage division encompasses regions in both WA and the NT. However, the socio-economic data provided in this section will pertain primarily to WA. The area covers about 564 647 km<sup>2</sup>, and is the second wettest drainage division in Australia, other rainfall is highly seasonal (CSIRO, 2009b). The population in the Kimberley, WA is estimated to be about 28, 298 with 12, 933 being Indigenous (46%) according to Carson et al (2009).

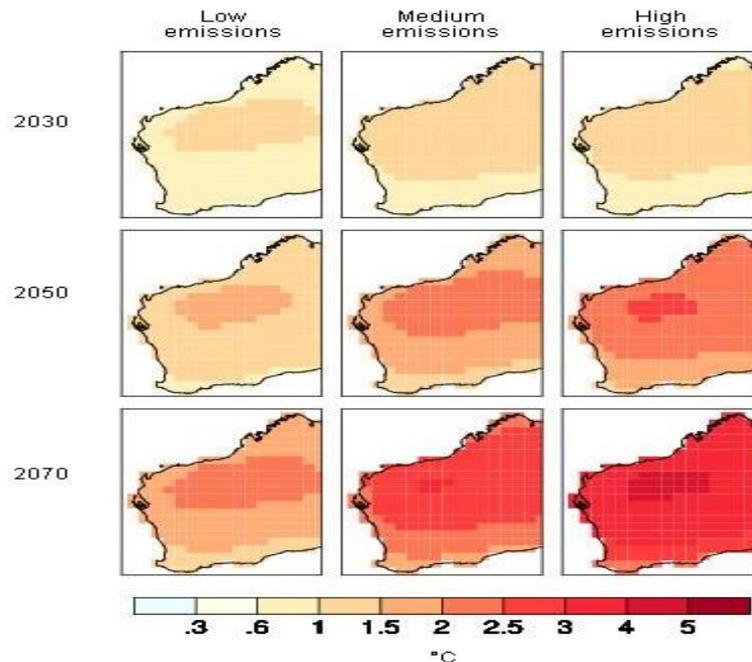
**Figure 16:** The Timor Sea Drainage Division and its Six Regions (CSIRO, 2009b)



### 3.3.1 Environmental Impacts

In a continent known for being hot, the Kimberley already experiences the highest temperatures in Australia. By 2030 it is expected that under a mid-range emissions scenario the annual average temperature of Western Australia will increase up to 1.5°C higher than the baseline average of the 1990's. Regional differences may become more marked in the future, so projections for temperature, rainfall and evaporation will be given for the northern regions of Western Australia relevant to this report. In 2050 the temperature is expected to increase by 1°C to 1.5°C for low and 2°C to 2.5°C for high emissions scenarios. Further increases are expected by 2070, with projected changes of 1.5°C to 2.5°C for low and 2.5°C to 4°C for high emissions scenarios. Green (2006) also suggests that the will see 1.5°C to 2°C temperature increase by 2050, with hotter temperatures expected inland for Kununurra, Wyndham and also Derby.

**Figure 17:** WA temperature changes (°C) for 2030, 2050, and 2070 (CSIRO and BOM, 2007a).



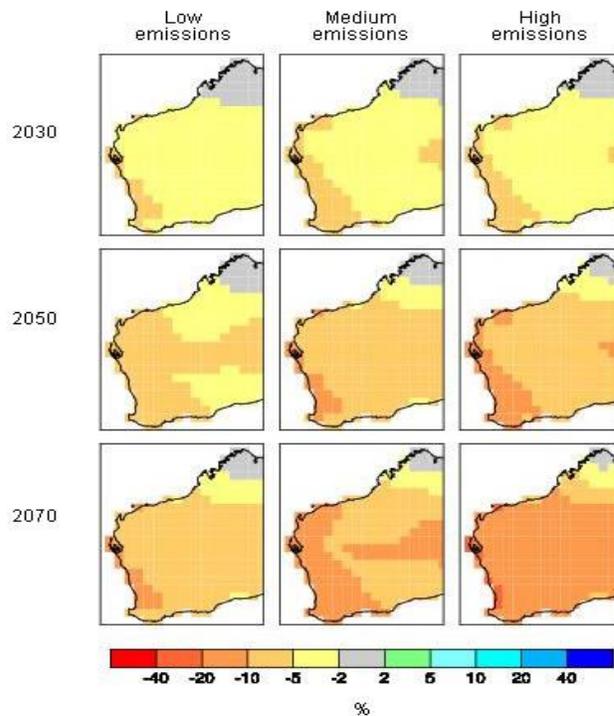
The number of hot days of +35°C in Broome are projected to increase from a current average of about 38 to 83 in a 2030 mid-range scenario, and in 110 (low) and 193 (high) in 2070 (Hennessy et al, 2010, in review).

**Table 8:** Number of +35°C Days per Year in Broome: 2030, 2050 and 2070. (Hennessy et al, 2010, in review)

Broome	Low (B1)	Mid (A1B)	High (A1F1)
(53.77)			
2030	-	<b>83</b>	-
2050	93	112	127
2070	<b>110</b>	148	<b>193</b>

Unlike many areas of Australia, the trend in north Western Australia since the 1970’s has been for rainfall increases of about 50 mm/decade (McKeon et al, 2009). In the future, while considerable uncertainty exists, the mid-range estimate is that northern Western Australia will see a -2% to +2% change in rainfall by 2030. In 2050 low emissions scenarios there is greater likelihood of up to -5% less rain in southerly regions around Broome, while a high scenario would possibly result in decreases up to -10%. Under a high emissions scenario in 2050 there is a chance that rainfall could decrease by -10% along the southern border of the TRaCK region, and this estimate remains similar for the 2070 low emissions scenario. The 2070 high emissions scenario could result in a change in rainfall of -20% to +2%. Green (2006) estimates a likely precipitation change of +/- 2% by 2050 and +/- 4% by 2100 in the Kimberley (Green, 2006).

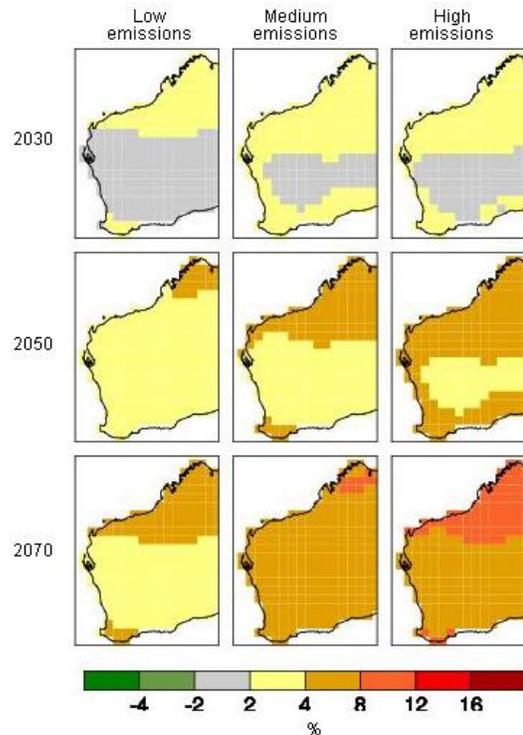
**Figure 18:** WA rainfall change (mm), 2030, 2050, and 2070 (CSIRO and BOM, 2007a).



The next figure demonstrates that increases in evapotranspiration will again exceed those of rainfall decreases by a great deal. Projections of evapotranspiration differ slightly from

those of the Northern Territory and Queensland. In 2030 a 2% to 4% increase is projected, but by 2050 (low) evapotranspiration could increase to 4% to 8% in northern Western Australia. This 4% to 8% increase is also projected for 2050 (high) and 2070 (low). By 2070 (high) projections are between 8% to 12%. The climate models indicate that evapotranspiration in the Western Australia portion of Northern Australia may become more pronounced earlier than in the Northern Territory and Queensland.

**Figure 19** WA Potential evapotranspiration 2030, 2050 and 2070 (annual, 50<sup>th</sup> percentile) (CSIRO and BOM, 2007a).



As with the other regions, the Kimberley is likely to be affected by more intense, but less frequent tropical cyclones (Abbs, 2009). It is projected that Broome and Derby will be exposed to higher cyclone risk than the rest of the Kimberley by 2050 (Green, 2006). Regions likely to be exposed to salt water inundation and erosion by 2050 include: Fitzroy River, Stokes Bay, Beagle Bay, Pender Bay, Walcott In., and Cambridge Gulf (Green, 2006).

Currently, the Kimberley contains about 80% of the divertible, fresh water resources in Western Australia, with most towns sourcing their water supply from bore-fields, although Wyndham is supplied by the Moolalabra Dam (Kimberley Development Commission, 2009). It is argued that tropical rivers are at high risk from rising sea levels, as well as the other impacts of climate change, and the potential impact of human adaptation to climate change may also be a significant threat (Hyder Consulting, 2008). Demands for agriculture and human consumption require actions such as water diversion and barriers that can further entrench ecosystem destruction (Hyder Consulting, 2008). The Fitzroy River system in the Kimberley is one of the key ecological assets of Northern

Western Australia, and is listed as being internationally important under the Ramsar Convention on wetlands (WWF, 2005). It is likely that the reductions in mangroves and increases in salt marsh areas between 1956 and 1999 in the Fitzroy system are a result of climate change, as the area is largely untouched by human activity (Duke et al, 2003). Another important ecological asset likely to be impacted by climate change are currently unspoilt and diverse tropical coral reef systems only recently discovered (Masini et al, 2009).

The biota of the Kimberley is similar to the rest of the Top End, especially Arnhem Land, rather than more southerly regions of Western Australia and contains a diverse array of ecosystems and animal life. The region's ecosystems are shaped primarily by climate and topography, with the complex topography of the North providing some refuge from climate change (Woinarski, 2001). Both rainforests and mangroves occur on the coast, a tropical savannah climate predominates in the sandstone and limestone ranges which give way to the drier southwestern lowlands of Dampier Land and the Daly Basin in the northeast (Woinarski, 2001). Although relatively untouched by development because of its isolation and inaccessibility, the impact of pastoralism and eradication of traditional aboriginal fire management has resulted in changes to native vegetation, which could be exacerbated by climate change (Woinarski, 2001). Habitat loss is one risk of climate change that could negatively impact the biodiversity of the region, especially through wetland loss due to sea level rise and changes in vegetation from increased heat and moisture stress (CSIRO MAR, 2006). The existing rich fisheries could experience shifts in location as well as reductions due to warming sea temperatures (CSIRO MAR, 2006).

### **3.3.2 Socio-Economic Impacts**

The social and economic impacts of climate change in northern Western Australia have not been subjected to the same amount of scientific research as Queensland and the Northern Territory. This section will thus provide a backdrop of the current social and economic status of the region, taken from the Kimberley Development Corporation (2009) unless otherwise indicated.

The population in the Kimberley was about 33 110 in 2007, which is about 1.6% of the total population in Western Australia, and was relatively younger than the rest of the state. The average annual growth rate of 2.2% from 1997 to 2007 was greater than the state average of 1.6%, and is expected to continue to grow. Nearly half of the population identifies as Aboriginal, with the greatest concentration in the Shire of Halls Creek. The largest industry employers in the Kimberley are Health Care and Social Assistance (15.8%), Public Administration and Defence (13.5%), Retail Trade (9.1%) and Education and Training (8.9%).

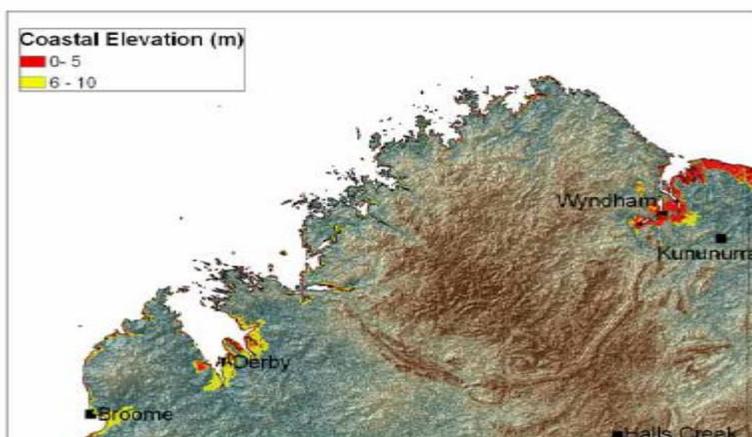
The primary agricultural area in the Kimberley is around the Ord River Irrigation Area (ORIA) of 14 000 hectares near Kununurra. It was estimated by the Department of Agriculture and Food that the ORIA contributes about \$87 million annually and plans are currently under way to expand the ORIA up to 28 000 hectares. The primary products are food crops such as melons, mangoes, pumpkins and chickpeas, and tropical forest

products such as Sandalwood. The region is far from danger of over allocation for irrigation, as only 3% of Lake Argyles reserves are used annually (Madden, 2008). Pastoral leases are held over most of the region and provide employment in remote areas, especially for aboriginal people, who run about a third of the pastoral stations. It is likely that pastoralism occurring in inland areas is more likely to experience reductions in water supply. The rich wild fish stocks around the Kimberley maintain an industry centred on finfish, prawns, barramundi, shark and threadfin salmon. The fishing industry is augmented by aquaculture, particularly the pearling industry but also harvesting barramundi in Lake Argyle. As with the rest of northern Australia, warming sea temperatures and extreme weather events are likely to disrupt wild fish stocks.

Although accounting for less than 600 jobs, the mining industry is by far the greatest contributor to the regional economy, generating \$991 million (2006/7) of the total \$1.78 billion gross regional product (2007/8). The Argyle Diamond Mine is the world's largest supplier of diamonds and nickel and iron continue to be mined. Mining operations could be impacted by restricted water access and increased intensity of severe weather events, as well as increasing electricity requirements for air conditioning during heat waves (LandLearn NSW, 2010). Significant offshore oil and gas reserves 400 km from Broome could be of great economic benefit, but control and extraction of the reserves has not yet proceeded. Tourism is an important industry, worth \$257 million per year to the region. In the Kimberley, tourism could be negatively impacted by the discomfort associated with extremely hot days which could seriously impact the regional economy.

As with the Top End regions in the NT and Queensland, coastal areas and infrastructure in the Kimberley are vulnerable to inundation and erosion from sea level rise and extreme weather. This could result in increased infrastructure costs for roads and bridges, as well as possible relocation in high risk areas. There is also the possibility of sewage and water supply problems (CSIRO MAR, 2006).

**Figure 14:** Low-lying coastal areas in the Kimberley's with areas below 5 meters in elevation in red, and between 6 and 10 meters in yellow. (CSIRO MAR, 2006)



Human health is likely to be negatively impacted by the predicted increase in temperatures in the Kimberley, with an even greater risk of heat-related illnesses and death than was discussed for the other regions given the lack of services in many remote areas (CSIRO MAR, 2006). Murray Valley encephalitis (MVE) is endemic in the Kimberley region and it is thought that climate change impacts such as increased temperature and intensity of weather could extend the current range and result in more frequent epidemics (Currie, 2001). Dengue and Ross River fever are also likely to spread as mosquito territory expands (CSIRO MAR, 2006). Again, water and food borne diseases as well as the chance of injury or death from increased intensity of extreme weather events and flooding are also likely to increase in the future (CSIRO MAR, 2006).

## **4. Adaptation**

### **4.1 Climate change adaptation**

Adaptation involves the transformation of social, ecological and economic systems to deal with physical and social change. Adaptation for social and economic systems occurs through coordinated or independent actions by individuals, groups or governments. According to Adger et al (2005) “adaptation is continuous stream of activities, actions, decisions and attitudes that informs decisions about all aspects of life, and that reflects existing social norms and processes” (78). Adaptation to climate change has been defined as the:

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation. (IPCC TAR, 2001)

Adaptation responses to climate change can be separated into two parts according to Adger et al (2005). First, there are efforts to support adaptive capacity; and second is the making of adaptation decisions. The overarching aim the authors suggest is to encourage the transformation of adaptive capacity into action to address climate risk. Adger et al (2005) identify three cornerstones to adaptation to climate change:

- (i) Reducing the sensitivity of a system to climate change (i.e. increasing dam capacity or irrigators planting more resilient crops)
- (ii) Minimising exposure of a system to climate change (hazard reduction)
- (iii) Supporting increased resilience of a system to cope with changes (e.g. improve wellbeing of individuals)

The position of the Australian government is that climate change is now unavoidable and future change is inevitable given the serious risks that are projected in Australia (Australian Government, 2010). Adaptation is currently informing decision processes and

policy making within the government, however, it is strongly felt that adaptation is a responsibility and challenge that must be also be shared with the business and community sectors (Australian Government, 2010; Garnaut, 2008). It is also felt that individuals and communities are best placed to manage the risks that they will experience in an efficient manner. The logic behind this reasoning is summarized below in an excerpt taken from the Garnaut Review:

“Some may expect that government can, and should, protect the community from climate change by implementing the right strategy, program or initiative to allow Australians to maintain established lifestyles. This is not a realistic expectation for four reasons. First, climate change will require adjustment of innumerable, locally specific customs and practices over time. Second, the range and scale of impacts that is likely across Australia is such that it is not feasible for governments to underwrite maintenance of established patterns of life for all people in all places. Third, the uncertainty surrounding climate change impacts makes it impossible to predict their timing, magnitude or location with precision.

Finally appropriate responses to climate change impacts will be specific to circumstances. In many instances, centralized government will lack the agility to orchestrate a differentiated response with the necessary precision to address local needs. The informational requirements of government would be extreme and costly. It unlikely that an intrusive or directive approach to adaptation would be as effective as one motivated by local interests.” (Garnaut, 2008: 364).

In a nutshell, the Australian Government intends to play their “important role in creating the right conditions and incentives for businesses and the community to make efficient investment decisions and manage risks from climate change impacts” (Australian Government, 2010: 8). Scientific knowledge generation, leading national reform, managing Commonwealth assets, and maintaining a strong economy and social safety net are the primary responsibilities of the Government. National priorities for climate change adaptation include: Coastal management, water, infrastructure, natural systems of national significance, natural disaster preparedness, and agriculture. Climate change adaptation will require continual incorporation and evaluation of new information to assist individuals, communities and businesses in their adjustment to the impacts of climate change.

As discussed earlier, Governments have a statutory responsibility to manage common resources (like water) and often governments or a government corporation manage public infrastructure.<sup>4</sup> Adaptation measures for infrastructure seek to improve robustness of design. There are costs attached to improving the design of infrastructure and there is a strong reliance on the accuracy of climate models (Hallegatte, 2009).<sup>5</sup> Hallegatte (2009)

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<sup>4</sup> This responsibility generally does not extend to irrigation infrastructure which is usually managed by cooperatives and their members (like the Ord Irrigation Cooperative in Kununurra, WA).

<sup>5</sup> Hallegatte (2009) considers five broad strategies relating to adaptation (as it relates to long term investments such as infrastructure) (i) a ‘no regrets’ strategy (ii) reversible and flexible options (iii) buying

cautions that adaptation cannot rely on climate models to be completely accurate, but these models can help decision makers anticipate changes (potential events) in design standards which can mitigate risk for infrastructure. While for water resource management a stated national objective is to optimize economic, environmental and ecological outcomes (Connell et al, 2005). This requires the development of policies, institutions and regulations to support this optimization, particularly in light of climate change. Coordinating adaptation measures for water and infrastructure across scales is costly and fraught with difficulties.

Coordinating adaptation across scales is constrained by differences in institutional arrangements, property rights regimes, social norms and diverse biological and ecological systems (Adger et al, 2005). This holds true for adaptation across a large area such as northern Australia. There is a lack of data on water resources, where little is understood about groundwater, or surface and groundwater interaction. Aside from the information gaps on water resources, there are differences in institutional arrangements across the diverse north, with differences in terminology and legislation that may hamper cross-jurisdictional adaptation in water resource management.<sup>6</sup> Two of the three jurisdictions, WA and Queensland, are focused politically and economically on their southern capitals. Most work on climate change and hydrology research has been focused on these metropolitan centres. There has been relatively little work across the north to understand the effect of climate change on water resources. This lack of knowledge serves to constrain adaptive capacity to the effects of climate change on water resources because such efforts must be underpinned by science to inform water planning efforts (Kiparsky et al, 2006).

## ***4.2 Adaptation and water resource management across the north***

Climate change will dynamically affect the hydrological cycle (UNDP, 2010). Our analysis of climate impact literature highlights that there is a real potential for increasing periods of water deficit through higher temperatures and evapotranspiration rates across northern Australia. Population projections also show strong growth (Carson et al, 2009), pointing to increased demand for water with potential supply constraints. While there will be regional variations, generally these trends point to decreasing water availability and increased risk to economic, social and ecological systems. As well, the threat of high rainfall and more intense cyclonic events suggest greater risk to life and property, with water resources infrastructure particularly susceptible to flood and cyclone. If water becomes scarce across the north the need to manage water sustainably through a robust and adaptive framework will become increasingly important. A planning and risk sharing

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“safety margins” in future investments (iv) promote soft adaptation strategies (v) reducing decision time horizons.

<sup>6</sup> Despite the NWI introducing a common framework there remain differences in terminology. Efforts for inter-state trading have only taken effect in southern states.

framework informed by best available science and community consultation can support sustainable outcomes. Given the inherent uncertainties linked to the effects of climate change, adaptive management is key to maintaining good outcomes.

The Northern Australia Land and Water Taskforce (2009) provides a series of recommendations to assist in the adaptation of northern Australian water management. They suggest that the NWI provides a valuable framework for addressing conflicts between competing interests as well as offering a template for sustainable water management. Building on this framework would ideally ensure that:

- All water extractions or diversions are subject to water planning processes;
- Water licenses and entitlements are only issued once NWI-compliant water plans have been established;
- Water trades (permanent and temporary) only occur within the boundaries of a particular river catchment or groundwater aquifer; water trades should not involve intercatchment transfers;
- Caps on water use for river and groundwater systems in northern Australia are set at conservative levels, reflecting limited knowledge and uncertainties, where caps should be reviewed as the knowledge base improves;
- Water plans include an assessment of all uses and values within a catchment, including the consumptive and non-consumptive use of water;
- Water plans are developed with local stakeholders, matching local circumstances and incorporating adaptive management principles and practices;
- Water plans include assessments of strategic environmental impact and take account of cumulative impacts;
- Planning and management of northern water resources are based on hydrological boundaries, either river catchment or groundwater basin boundaries; and
- The capacity of local, regional, state and territory, and national institutions is improved.

(Northern Australia Land and Water Taskforce, 2009: 31)

Additional recommendations address the inconsistencies in policies, land tenure and water entitlements across the three regions. It is felt that effective adaptation will require increased flexibility and harmonization of policies and land/water use in the North to

support new initiatives. A crucial component of this kind of integrated management is the recognition of Indigenous people's rights and interests in water; cultural, social and economic needs must be accounted for in allocating water rights (Northern Australia Land and Water Taskforce, 2009: 32).

Adaptation for water resources management requires an integrated approach. Krysanova et al (2010) developed an eight point integrated framework for climate adaptation strategies in river basins in Europe. The measures cover the following themes: climate information, infrastructure, agriculture, spatial planning, water resource management hard measures, water resource management soft measures, social measures, and information, communication and education. This framework highlights the multi-disciplinary nature of adaptation for water resources management, covering broad socio-economic issues. The social component of adaptation will be complex across the north given the prominence of Indigenous groups who are socio-economically disadvantaged and speak English as a second language. Water resource management has failed to adequately involve or consult with Indigenous groups across the north, so further work will be essential (Nikolakis et al, 2010). Increased stakeholder engagement and collaborative governance may be important institutional features to adaptation, as reflected by McKeon et al (2009) in the northern rangelands, that successful adaptation will be determined by the level of collaboration between local and scientific knowledge. Government is generally seen as central to adaptation measures, and there may be the potential for greater public involvement in water planning.

Inadequate water governance could further compound supply and demand pressures for water across the north, and it has been noted that water reform in Australia has been slowed by difficulties with implementation (NWC, 2009). In the north, inland river systems in particular are vulnerable to the pressures of development, as they rely on limited points of groundwater discharge which could be adversely affected by a hotter, drier climate (CSIRO, 2009a). The difficulties in water reform must be addressed to ensure equitable and sustainable distribution of water resources to commercial, environmental and cultural interests in the north (Northern Australia Land and Water Taskforce, 2009). Taking early action is seen as important, and adaptation is seen as crucial to reduce climate change impacts.

Water markets are one way to provide flexibility to users in light of environmental, social and economic changes, but they are at a formative stage across the north. The Garnaut Review argues that pursuing this goal of sustainable water distribution requires "water markets that are transparent, broad and flexible, and based on clearly defined property rights, [that] are better able to manage shocks" (Garnaut, 2008: 373). Water markets in southern Australia have given individuals increased flexibility to make production or allocation decisions. The NWC (2010) found that markets in the MDB have optimized economic, social and environmental values to water. Water trading supported productivity through the reallocation of water during drought (particularly inter-regional water trading). Economic modeling identifies a \$220 million increase in Australia's GDP through reallocations of agricultural water in 2008-9.

*Adaptation mechanisms in water plans across northern Australia*

Nikolakis and Grafton (2009) identify that jurisdictions in northern Australia have taken a precautionary approach in setting the extractive limits for systems in the north. There are significant information gaps on resource characteristics, as well as ecological and customary values which need to be addressed to meet sustainability objectives. Across northern Australia there are four completed water plans (see Table 9). One of the aspirations of the NWI was for water plans, informed by best available science and community consultation, to underpin a risk sharing and water trading framework (NWC, 2009). These plans should be supported in statute to ensure consistency. The NWI specifies that water plans should be adaptive to address environmental and public benefit outcomes (paragraph 25). The NWI also provides that plans should be subject to ongoing review and monitoring to support outcomes (paragraph 40). Table 9 provides an overview of plans in the tropical belt of northern Australia, how robust they are, and any adaptive measures employed around water sharing and allocation.

**Table 9:** Robust planning framework in each jurisdiction (adapted from Ward et al., 2009)

<b>Water Allocation Plans in North</b>	<b>NT (WAP)</b>	<b>QLD (WRP and ROP )</b>	<b>WA (Regional Plans and Water Management Plan's WMP)</b>
<b>Completed</b>	Tindall (2009)	Gulf WRP (2007) Mitchell WRP (2007) Gulf ROP (2010) Mitchell ROP (2010)	Ord River WMP (2006)
<b>Draft</b>	Oollo Mataranka		La Grange
<b>Duration of Plan</b>	10 years	10 years	3 years
<b>Plan Review</b>	< 5 years	< 10 years (WRP's)	7 years
<b>Statutory Plan</b>	Yes, the water allocation plan is statutory.	The WRP is enacted in statute.	No. (A Water Resources Management Bill provides for statutory plans).

<p><b>Adaptive measures</b></p>	<p>Yes, the plan may be amended any time without compensation. Also the risk assignment framework with statutory power to reduce allocation to zero (and impose restrictions on stock and domestic) provides flexibility each year.</p>	<p>Yes, there is a risk assignment framework in supplemented schemes to reduce entitlements. The ROP may be amended at any time or replaced by the Minister. The WRP, if replaced within first 10 years allows for entitlement holders to be paid reasonable compensation if the change reduces the value of the entitlement. Annual reports assess performance in meeting specific outcomes in plans (ss. 54-56 Water Act).</p>	<p>There is a statutory process to reduce allocation if there is impact on the environment or to respond to changing conditions. The Ord plan can be amended, revoked, replaced according to statute.</p>
<p><b>Allocation among consumptive users and the environment</b></p>	<p>A 20% limit is imposed on extraction and 80% must be left for the environment as a general guideline.</p>	<p>In QLD there are flow objectives determined by nodes at specific points in streams or rivers. The Chief Executive may impose conditions on allocation influenced by flow in unsupplemented surface water areas. In supplemented areas, announcements are made for allocation based on a water sharing index which is the mean of the percentage of number of months in the simulation period (a historic period) for each priority group (high to low security) that allocations are fully supplied</p>	<p>Allocation decision making determines the water required for Environmental Water Provisions and Ecological Water Requirements (EWR's). FLOWS methodology links values like EWR's and identifies whether they can be supported under various flow regimes (identified by level of Lake Argyle in the Ord). The Ord River Scientific Panel developed a scale for changes in the flow regime and impact on riparian values, with a 10% reduction in flow of least concern, and 25% of most concern</p>

<b>Climate change measures</b>	In the Tindall Water Allocation Plan it is conceded that knowledge of climate change is limited. The plan does not predict the possible effect of climate change on long term water availability- but suggests that the ability to reduce allocations on an annual basis can respond to changing water availability (Northern Territory Government 2009)	Recognition that changing climate and demand patterns will affect the performance of entitlements into the future in the Gulf Water Resource Plan- security objectives can change if water availability. Water allocation security objectives can reduce take effect in ROP to reduce water if there is scarcity (Queensland Government, 2007a)	Ord River Water Management Plan identifies that the implicit assumption “is that the future inflows to the Ord River Dam have the same statistical properties as the historic sequence.” (Department of Water 2006: 67) However, the report states that as climate change knowledge improves this assumption will be re-evaluated.
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Climate change is discussed in water plans only briefly. Plans state that as information on climate change becomes available plans will be amended, and there is flexibility to reduce allocations to consumptive users if water availability decreases. In the NT, the Water Controller can reduce allocations according to the security level assigned to entitlement holders. High security entitlement holders can expect more reliability than medium or low security entitlement holders. The Water Controller in the NT has the capacity to reduce allocations to zero in times of critical scarcity, and impose restrictions on unregulated ‘stock and domestic’ users. Water plans in the NT are reviewed after 10 years and allocations may be adjusted accordingly. In the Ord, extreme variability is not expected to occur often because of its storage capacity. Entitlements have 95% reliability in the Ord meaning irrigators can expect to get their full entitlement 95 years out of 100 years. In Queensland, plans provide for reduced allocations each year according if stream flow is reduced in unsupplemented systems. A water sharing index is used to decide allocations in supplemented systems (or regulated in NWI consistent terminology) at the beginning of each water year. In Queensland if the water plans are amended within the 10 year life and impact entitlement holders, compensation is payable.

Table 10 presents state and territory government strategies currently in place to deal with climate change adaptation and water adaptation. The Western Australian government recently established a Climate Change Response Strategy under the Department of Agriculture and Food that “consolidates information from across the Department to provide a balanced and coordinated strategic direction for climate change activities by identifying and prioritizing key actions to be achieved over the next five years” (Bennet, 2010: iii). The Northern Territory Climate Change Policy was established in 2009 within the Department of Chief Minister and Natural Resources, Environment and The Arts (NRETA) which is also responsible for water management. Queensland created an Office of Climate Change and has developed a Climate Smart Adaptation Plan from 2007-2012.

**Table 10:** State Government Climate Change and Water Strategies: WA, NT and Queensland.

	<b>Western Australia</b>	<b>Northern Territory</b>	<b>Queensland</b>
Name of Strategy	Climate Change Response Strategy (Bennet, 2010)	The Northern Territory Climate Change Policy	Climate Smart 2050
Duration	2010.	2009.	2007. Subject to ongoing adaptation.
Departments and Agencies	Department of Agriculture and Food oversees the Climate Change Response Strategy.  The Office of Climate Change (May 2007) was established within the Department of Environment and Conservation.	Department of Chief Minister and Natural Resources, Environment, The Arts and Sport (NRETAS)	Office of Climate Change, in the Environmental Protection Authority
Financial Commitment	\$6.5 million for climate change adaptation	\$34 million	\$1.3 billion (including government and industry contributions)

The WA climate change response strategy discusses that there is the potential from climate change for increased evaporation, which will require increased storage capacity or improved run off generation systems (Bennet, 2010). There is no direct discussion on the affect on water availability in the north, but the report does state generally across WA that there is likely to be reduced rainfall for agriculture, changes in temperature and altered growing seasons. This will have implications on the health of crops and livestock (such as increased disease, fungus etc) (Bennet, 2010). The report outlines that more research is required on climate change impacts, but that risk management tools can support adaptation in primary industries.

The NT Climate Change Policy (Northern Territory Government, 2009b) provides in Target 38 and 39 that the government will ensure water resources are managed sustainably. Target 38 provides the NT government will provide a leadership role in water use planning and allocation to respond to climate change impacts. Target 38 identifies actions to impose caps on extraction once a sustainable yield has been identified. The sustainable yield is to be influenced by best available science, and water entitlements will provide appropriate security levels. Security levels it is identified should

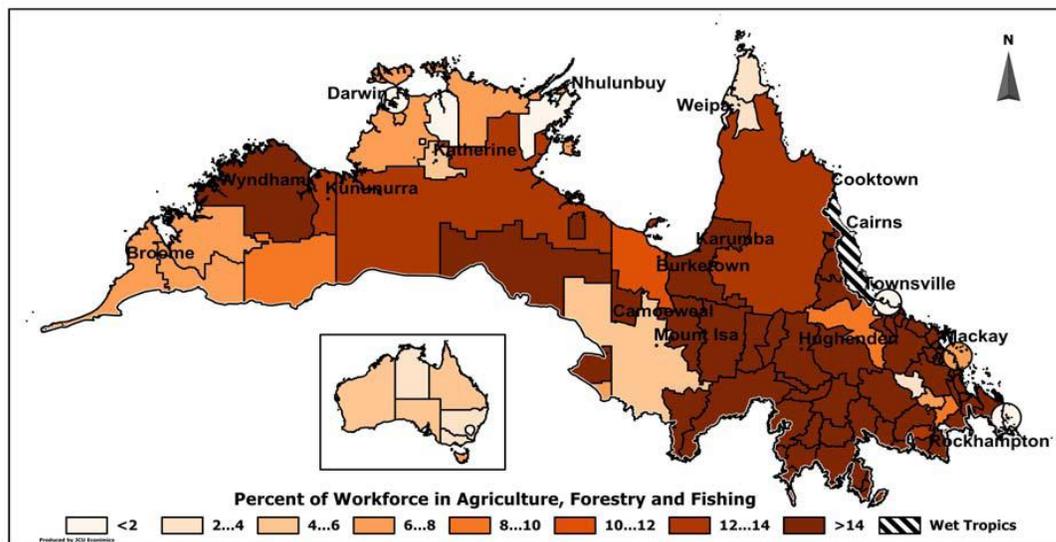
account for risks due to climate change. The public should be aware of the risk and security associated with entitlements (Northern Territory Government, 2009b).

In Queensland the Climate Smart Adaptation Plan (2007) identifies water planning and services as a priority, particularly to understand the risks associated with climate change impacts, and to foster resilience against these risks (Queensland Government, 2007b). The plan acknowledges the variability in water resources in the state, and water security is a major variability. However, it is acknowledged that this vulnerability is most acute in the heavily populated south-east of the state. The plan identifies the effect reduced water availability will have on other sectors important to Queensland’s competitiveness, including the tourism and agriculture sectors (Queensland Government, 2007).

### 4.3 Adaptation and agriculture

Agriculture is perhaps the industry most vulnerable to the impacts of climate change (Hodges and Goesch, 2006). Agriculture in the north contributes significantly to the economy and employment, with intensive irrigated agriculture worth about \$160 million and beef production valued at over \$1 billion (Northern Australia Land and Water Taskforce, 2009). It is also estimated that based on groundwater availability, less than half of the total available area for groundwater irrigated agriculture is currently being used (20 000 of a potential 40 000-60 000 hectares) (Northern Australia Land and Water Taskforce, 2009). Strengthening agricultural adaptation in the North requires a more thorough understanding of the water, land and soil resources available, as well as where salinity risks exist. Knowledge of environmental details provides the foundation for progressive management, but other areas must also be addressed.

**Figure 15:** Percent of workforce in Agriculture—by postcode Data Source: ABS CDATA 2001 (Sourced from Stoeckl et al, 2007: 39)



Implementation of adaptive frameworks and policy in the agricultural sector requires an understanding not only of biophysical vulnerabilities, but also of the socio-economic vulnerabilities (Pearson and Langridge, 2008). Many remote communities across the north are dependant on various forms of agriculture, with farmers playing an important role in rural water and land management. Pearson and Langridge (2008) describe the lack of comprehensive knowledge about agricultural vulnerability to climate change, especially on a regional basis, and regarding contextual factors. They suggest that a concerted effort must be made to address the lack of contextual information that will be crucial for regional adaptation efforts. Three areas are highlighted in their report:

- Vulnerability must be assessed within specific contexts and populations to inform practical action;
- A contextual vulnerability research agenda must be implemented which embeds current linear response modeling into decision making and policy processes leading to mitigation and adaptation actions; and
- Multidisciplinary and cross-institutional teams must be built to bring together social and biophysical scientists and economists to understand the processes and governance of change.

(Pearson and Langridge, 2008: 21-22).

These recommendations illustrate the importance of a multidimensional approach to agricultural adaptation given the social impacts associated with the industry.

#### ***4.4 Adaptation and Pastoralism***

Like cultivated agriculture, pastoralism is likely to be threatened by future increases in droughts and lower summer rainfall, as well as extreme weather events provoking flooding and salt water inundation (Cobon et al, 2009; McKeon et al, 2009). These impacts will negatively impact beef production by reducing pasture and surface water availability; addressing these impacts requires greater understanding of regional vulnerabilities to inform the transitional changes needed (Cobon et al, 2009). A significant factor for pastoralism is accurate knowledge of climate risk assessments, including seasonal climate forecasting, to allow informed adaptation policies to be effectively enacted (McKeon et al, 2009). In their review of adaptations available to the grazer industry in the north, Cobon et al, (2009) conclude that ongoing eco-physiological research is required for communities to proactively deal with climate change impacts. They also suggest that a risk-management approach involving “risk assessment, risk statements, the regional evaluation and feedback, proposed training and tools” will allow regional adaptation needs to inform broader scale policy and institutions (44).

In addition to the scientific requirements of adaptation, there is also support for harmonization of water and land tenure and policies to promote successful adaptation

measures. In relation specifically to pastoralism, the Northern Australia Land and Water Taskforce (2009) argue that:

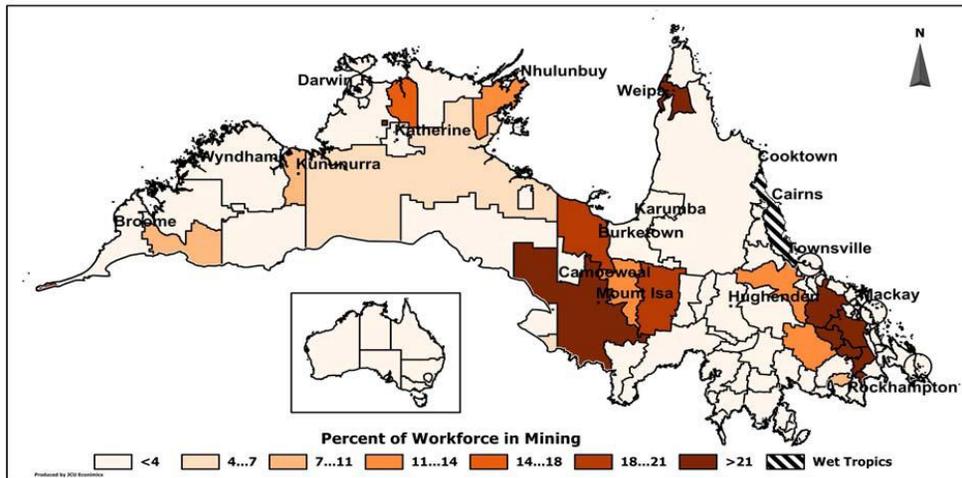
‘Australian governments should adapt and harmonize pastoral lease conditions (including on Indigenous land) across northern Australia to allow greater diversification and flexibility in land use, subject to compliance with the principles of ecologically sustainable development, the objectives of the National Water Initiative and the ongoing coexistence of native title rights.’  
(Northern Australia Land and Water Taskforce, 2009: 4).

Addressing environmental and policy factors related to pastoral adaptation are important, but are incomplete without acknowledging related social and cultural issues. Pastoralism is of great importance to many remote communities, especially the aboriginal population. Possible land use change must also address the social and economic requirements of individuals and communities dependant on the industry (Pearson and Langridge, 2008).

#### ***4.5 Adaptation and Mining***

The mining industry may not typically be considered at risk due to climate change; however, adaptation in several areas is likely to be necessary for many mining operations. Hodgkinson et al (2010) describe that the production stage of mining operation is most likely to be negatively impacted by increased temperatures and extreme climatic events. Water availability is seen as a potential threat in regions with scarce water supply, making utilization of more efficient technologies important to reduce water supply pressures. Where the climate becomes wetter or hotter risks to equipment and personnel safety increase as equipment malfunction becomes more common (Hodgkinson et al, 2010). Adaptation measures that would be helpful could include more frequent equipment and site inspections, as well as contingency plans to ensure the health risks to employees are minimized during extreme, hot and wet conditions. Also, increased education and knowledge of local water and energy supplies could reduce the potentially harmful impacts of climate change on mining operations (Hodgkinson et al, 2010).

**Figure 16:** Percent of workforce in mining—by postcode Data Source: ABS CDATA 2001 (Sourced from Stoeckl et al, 2007: 40).



#### 4.6 Social Aspects of Adaptation

Beyond the focus on environmental and institutional factors there is also the need to address social issues involved in building adaptive capacity. Moore and Archer (2009) argue that a paradigm shift is required not only in water management policy, but also in public perceptions of how drought is to be mitigated in the agricultural sector. They propose that a new social consensus is needed on how to respond to the impacts of climate change. While their focus is on the agricultural sector, the model they propose would also be relevant to other industries impacted by a changing climate. In their model there are four primary social spheres with an interest in the impact of climate variability on agriculture. These include:

- Individuals and Families: well being directly related to farm business
- Communities: Wellbeing closely tied to agricultural fortunes
- Industry: Dependant on agriculture for viability
- Land and Water: Managed by farmers, including ecosystems.

Each of these spheres will have unique interests and goals, and it is the mutual recognition of these different priorities that constitutes a significant part of the consensus building needed for socially responsive adaptation policy. The authors argue that water management has moved beyond the natural disaster and risk management paradigms previously used. The new paradigm requires building a *new social consensus* through the active involvement of multiple spheres of interest. Fundamental social principles underlying consensus building are to “prevent unacceptable loss of well-being for individuals and families”, and to see that they are “empowered by governments to manage change according to their individual circumstances” (Moore and Archer, 2009:

15). It is acknowledged that consensus building is a long term endeavor requiring active participation and discussion.

The health and social impacts of climate change have already been discussed, but it is important to recognize that changing climate conditions will disproportionately affect already marginalized populations. Remote aboriginal communities have been described as having a reduced capacity for adaptation for a variety of reasons including environmental exposure, poor infrastructure, lack of health, social and employment services, and lower socio-economic status (Green, 2006). Effective adaptation in remote communities will likely require increasing knowledge of local capacity and social, cultural and economic interests (Robinson et al, 2009). Promising initiatives that could build adaptive capacity and simultaneously resolve environmental degradation include various Indigenous land and sea management activities (Putnas et al, 2007). Such enterprises have been seen to provide community benefits including “a broad range of environmental, cultural, social, education, health, employment and economic development outcomes” (Putnas et al, 2007: 8).

This overview of environmental, institutional and social factors involved in climate change adaptation in agriculture underscores the importance of integrated approaches cognizant of a broad range of interests and issues and transparency in implementation.

## **5. Conclusions**

Climate models highlight the potential for higher temperatures and evapotranspiration rates across northern Australia. Population projections also show strong growth, particularly for centres such as Darwin. These factors point to increased demand for water coupled with supply constraints. A robust and adaptive framework will become increasingly important, consistent with the NWI; a planning and risk sharing framework informed by best available science and community consultation offers the potential of sustainable outcomes. Water stress creates risk to economic, social and ecological systems – the potential impacts on these systems are not well understood in the region. In Queensland and WA much of the climate research has been focused on their populated southern regions. Recent work by CSIRO and BOM (2007a) and CSIRO (2009a) in the north predicts a heightened threat of more intense rainfall and more intense cyclonic events. In some coastal areas the potential for saltwater inundation is likely to increase, and in inland areas the potential for drought and fire may increase in frequency. This suggests an increased risk to life and property, with water resources infrastructure particularly susceptible to flood and cyclone. Climate models can allow policy makers to anticipate events and this can inform design standards (Hallegatte, 2009).

Uncertainty is a major constraint for policymakers in developing adaptation decisions for water resources. Water plans and adaptation policies in each jurisdiction reflect that climate change will have an impact- but there is limited data on the location and type of impacts, which constrains proactive planning. Developing the institutional arrangements for water markets is one way to enable adaptation. In southern Australia, water markets have provided flexibility to irrigators in times of drought and allowed irrigators to

maintain productivity during water scarcity. The ability to trade water exists in northern Australia, but there have been no trades to date. The main mechanism to address climate change in water markets is the flexibility provided to reduce allocations according to security of entitlement. As water availability reduces, water managers can reduce the level of allocation to entitlement holders. Plans are able to be reviewed and the consumptive limit may be altered to reflect changing conditions. As more data becomes available there is the potential to integrate climate data into water plans, which shall influence consumptive use and water trading rules.

The social aspects of adaptation as they relate to water resources will require attention. The existence of a large Indigenous population who are subject to disadvantage and often speak English as a second language may constrain activities to support adaptation— education and awareness on climate change impacts are important to encourage adaptation in social systems. The impacts of climate change are not distributed equitably, being felt most acutely by those disadvantaged— to maintain principles of equity, policy makers should support efforts to encourage Indigenous resilience and access to water.

There are constraints to implementing adaptation across scales like the north Australian region, given the difficulties in coordinative planning across diverse legal and ecological systems. There may be impacts on the pastoral and agricultural industries across the north from drought, such as reduced feed quality and water availability for the extensive pastoral industry in the region. Important to adaptation in socio-economic systems is close collaboration with stakeholders in developing adaptation programs— local knowledge is important in supporting outcomes. However, more work will be required to include Indigenous groups in collaborative efforts. As more data is available, an integrated approach to adaptation in water resources management is essential, reflecting the need for a whole of government approach, which is flexible and collaborative in nature.

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