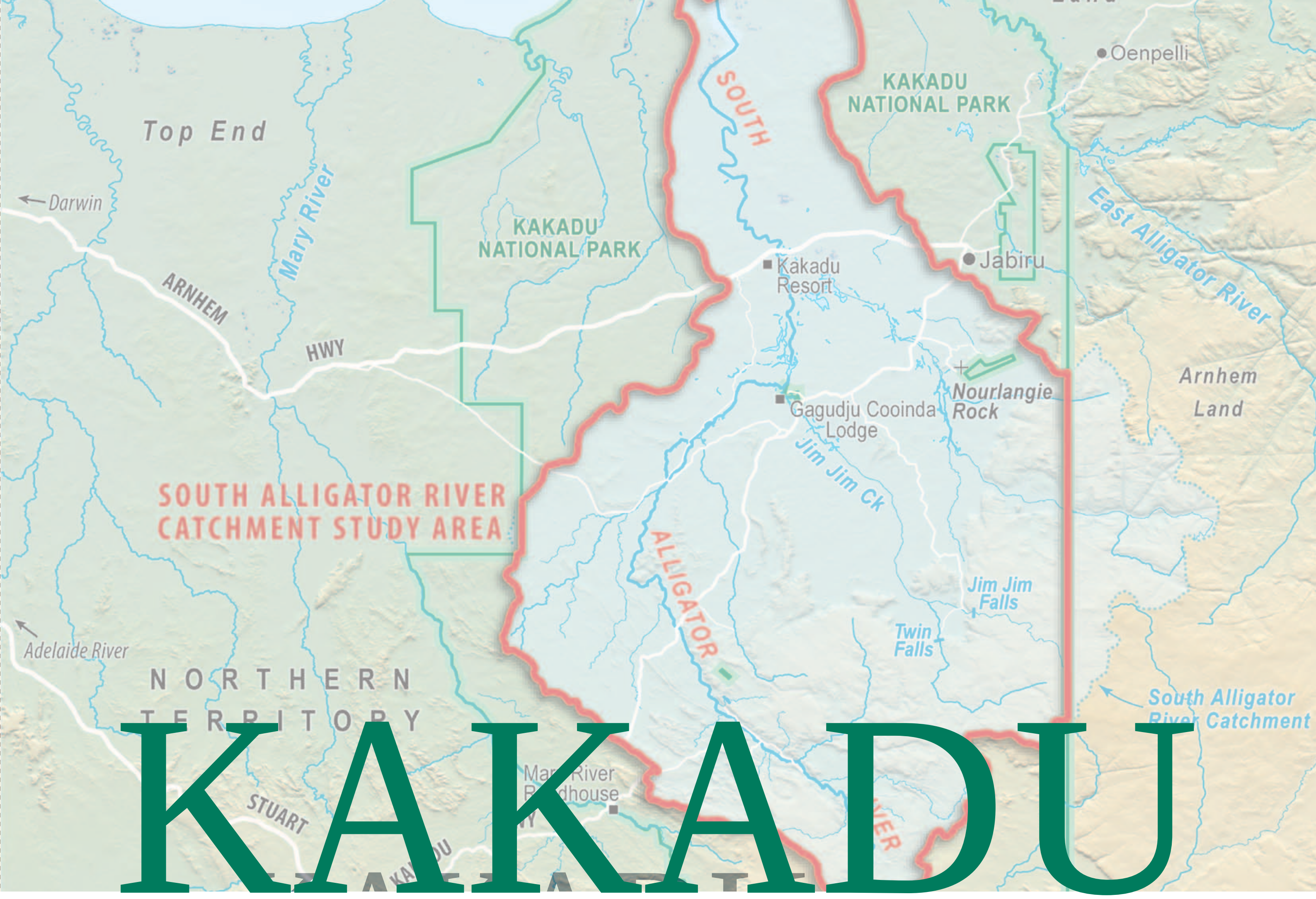

KAKADU

Vulnerability to climate change impacts

A report to the Australian Government Department of Climate Change and Energy Efficiency

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BMT WBM

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Kakadu-Vulnerability to climate change impacts
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Aerial view of South Alligator River, Kakadu (Flemming Bo Jensen)

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Glossary

Accretion	Describes addition of sand to a deposit such as a beach, dune, spit or barrier
Adaptation option	Measure or action developed to treat an identified risk
Aeolian erosion	Applied to deposits of material transported and arranged by the wind
Alligator Rivers Region	The region in the Northern Territory which is centred on the South Alligator River, includes the East and West Alligator Rivers and the Kakadu National Park
Alluvium	Sediment deposited recently by rivers
Asymmetric tide	The reshaping of the tidal wave from a simple sine curve in deep water to a curve with steeper and milder slopes in shallow water
Bathymetry	Topography of the ocean floor
Bininj	The term Bininj is used to refer to traditional owners of Aboriginal land and traditional owners of other land in Kakadu National Park, and other Aboriginals entitled to enter upon or use or occupy Kakadu National Park in accordance with Aboriginal tradition governing the rights of that Aboriginal or group of Aboriginals with respect to the Park.
Catadromous	A species of fish that lives in freshwater but migrates to marine waters to breed
Cheniers	Water deposited ridges resting on clay or mud deposits along a seaward facing tidal shore
Dendritic channel	An ephemeral channel formed when freshwater draining from the catchment scours a channel through the levee and subsequently is filled with tidal water. The channels can be short lived and self-heal by the same process that builds the levees
Environmental value	Habitats or species that are considered representative of key ecosystem components, processes and services within the study area. The significance of Environmental Values may be in terms of biodiversity/ecosystem values and/or human use values
Ephemeral	Short-lived, or of brief duration
Fluvial processes	Applied to deposits of material transported by rivers and streams
Geomorphology	Science that treats the general configuration of the earth’s surface and changes over time due to physical processes such as wind and tide
Holocene	Refers to the geologic period from 10000 years ago to the present
Levee	Small bank formed beside the river channel in the upper estuary by silt deposited when tidal water overtops the bank and flows onto the floodplain
Macrophyte	An aquatic plant that grows in or near water, and has an emergent, submerged or floating growth form
Morphology	Description, observation or explanation of the form of the land
Multiple criteria analysis	A process approach to decision-making during which information, of a scientific as well as social and economic nature, about the problem to be addressed is integrated in an evaluation exercise to prioritise action
Pan evaporation	A measurement that combines or integrates the effects of several climate elements temperature, humidity, solar radiation and wind. For the South Alligator River region pan evaporation greatly exceeds rainfall

Paleochannel	An old channel that was historically part of the tidal system. During large runoff events the relatively large flows can create new channels and isolate parts of the old channel
Pleistocene	Refers to the geologic period between about 2 million years and 10000 years ago
Potadromous	A species of fish that undertakes breeding or dispersal migrations wholly within freshwater
Progradation	Advancement, usually over a long term, of the shoreline in a seaward direction, by the addition of sediment
Recession	Landward movement of the shoreline, usually as a result of erosion
Reduced Level	A term referring to a level which has been measured from a datum e.g. AHD
Relict	Refers to a topographic feature that remains after other parts of the feature have disappeared
Risk assessment	The overall process of risk identification, risk analysis and risk evaluation
Sediment	Solid material, both mineral and organic, that is in suspension, is in the process of transportation or has been moved from its site of origin by air, water or ice, and has come to rest on the earth's surface either above or below sea level
Seepage zone	A zone beneath the surface which carries a significant flow of water which may or may not reach the surface
Sickness Country	An area of land in the southern end of Kakadu National Park associated with the Bula tradition, with particularly high cultural significance and strict rules and protocols associated with accessing and using the area. Special provisions regarding the management of Sickness Country are in the lease agreement between the Director of National Parks and Gunlom Aboriginal Land Trust.
Stillstand	Refers to a geologic time period when mean sea level remains relatively constant; the most recent occurrence of this phenomenon occurred approximately 6000 years ago
Stratigraphy	Study of the geographic position and chronologic order of sequence of geologic strata
Symmetric tide	The tide progresses in the form of a sinusoidal wave. In deep water this wave shape does not change but when the tide moves into shallow water the shape becomes asymmetrical (see Asymmetric tide)
Tidal deposition	Because of the asymmetry of the tidal wave it is able to carry more suspended sediment in one direction. In the case of the South Alligator River marine silts are carried towards the upper estuary.
Tidal drainage	This term refers to the drainage of billabongs and other water holding areas
Tidal scour	Tidal scour is the process whereby the high currents associated with the large tidal range in the South Alligator River causes scour or movements of the silty sediments
Wetting up (of the catchment)	The early rainfall on a dry catchment soaks into the ground surface and does not form part of a runoff flow

Acronyms

AHD	Australian Height Datum
AIMS	Australian Institute of Marine Science
ALGA	Australian Local Government Association
ARR	Australian Rainfall and Runoff
ATAP	Australian Tourism Accreditation Program
BP	Before Present
CAMBA	China-Australia Migratory Bird Agreement
CBA	Cost-Benefit Analysis
COAG	Council of Australian Governments
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCCEE	Australian Government Department of Climate Change and Energy Efficiency
DEM	Digital Elevation Model
DSEWPaC	Department of Sustainability , Environment, Water, Population and Communities
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ERA	Energy Resources Australia
EV	Environmental Value
HAT	Highest Astronomical Tide
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JAMBA	Japan-Australia Migratory Bird Agreement
KNP	Kakadu National Park
KRA	Key Result Area
LAT	Lowest Astronomical Tide
LCNT	Land Care Northern Territory
LGAQ	Local Government Association of Queensland
MCA	Multiple Criteria Analysis
NCRA	National Coastal Risk Assessment
NHT	National Heritage Trust
NLC	Northern Land Council
NRETAS	Northern Territory Department of Natural Resources, Environment, The Arts and Sport
NT	Northern Territory
NTG	Northern Territory Government
RL	Reduced Level
ROKAMBA	Republic of Korea-Australia Migratory Bird Agreement
SAR	South Alligator River
SEA	Systems Engineering Australia Pty Ltd
SLR	Sea Level Rise
SRES	Special Report on Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
TO	Traditional Owner
UNESCO	United Nations Educational, Scientific and Cultural Organization

Executive Summary

This case study examines the potential impacts of climate change and sea level rise on the South Alligator River system, one of Australia's most valued, natural, and cultural landscapes. The South Alligator River is located within the Northern Territory's Kakadu National Park which receives international recognition and is listed as a World Heritage area and Ramsar site (fig. ES-1). Kakadu is one of Australia's natural ecosystems most vulnerable to the impacts of climate change, with saltwater intrusion a serious risk to its freshwater wetland systems.

Modelling undertaken in this study under climate change scenarios for 2030 and 2070, suggests that future saltwater intrusion within the South Alligator River is likely to occur due to increased tidal pressure on dendritic channels and increased levee overtopping. Other findings include a significant change in the number of days each year classified as either 'wet' or 'dry' days, and a significant alteration in the frequency, duration, and extent of large floods.

Climate changes for 2030 and 2070 are expected to impact on the key environmental, cultural, and economic values of the study area. Environmental values such as native species (migratory and threatened) are likely to be affected by a decrease of the extent of freshwater flora and abundance of fauna, which may also impact upon cultural values due to a decrease in species of cultural significance (e.g. for bush tucker). Further impacts to cultural values may include reduced access to country (including sites of cultural significance), as well as reduced recreational opportunities for local people and tourists. The regional economy may also be impacted by changes to the environmental values. Tourism makes a significant contribution to the regional economy, and a decline of Kakadu's environmental values could result in reduced numbers of visitors to the region. In concluding the study, the performance of potential adaptation options against a 'do nothing' approach was assessed.

THE SOUTH ALLIGATOR RIVER CATCHMENT

The catchment of the South Alligator River extends from the coastal floodplains in the north of Kakadu National Park, to the sandstone plateau in the south, covering 11,700 km^2. Located in the monsoonal zone of northern Australia, the area experiences annual extremes of the wet and dry cycle. The freshwater and saltwater systems of the South Alligator River exist in dynamic equilibrium, made complex by the relatively high tidal range, high seasonal rainfall and high natural variability. The tidal interface is subject to constant change caused by channel contraction and expansion.

These complex processes underpin the ecological, cultural and socio-economic values of the South Alligator River catchment. Many of the cultural and socio-economic values of the catchment are dependent on the maintenance of ecosystems and the conservation of biodiversity.

The traditional owners of Kakadu are the Bininj. It is estimated that the Bininj have occupied the Alligator Rivers region for up to 60,000 years. At the time of European arrival in the area, it is predicted the Bininj population of Kakadu was about 2,000, of which 600-900 hunted and gathered around the wetlands of the South Alligator River south of Nourlangie Creek.

Approximately half of Kakadu is Bininj land, whilst the remainder is land under claim. The Bininj have leased their land to the Director of National Parks in order for it to be managed as a national park. A joint management arrangement enables Bininj to look after their country in cooperation with Kakadu National Park staff, providing the Bininj with opportunities to be consulted, make decisions, and implement these in the management of Kakadu National Park.

THE FLOODPLAIN

The South Alligator River floodplain including the main river channel between Yellow Water wetland and the coast, is the conduit through which annual freshwater flows. The flow can be in excess of 3,600 gigalitres per year (or more than seven times the volume of Sydney Harbour). The floodplain is extremely flat with falls of only 1-2 metres in over 100km. Depressions created by historic channel alignments and settlement of previous marine deposits are filled with freshwater during the wet, and evaporate during the dry. This retention of freshwater in billabongs, paleochannels and other features is the key factor in maintaining the ecological diversity of the region and its attraction to traditional owners and, more recently, tourists.

Figure ES-1: Case study location

METHODS AND IMPACTS ON CATCHMENTS AND FLOODPLAINS

The principal objective of the Kakadu case study was to use modelling to assess the risk of saltwater intrusion and extreme rainfall events on low-lying coastal wetlands, and to determine the implications for planning, management and policy.

The study was conducted in six key stages:

- Identification of key processes and values
- Development of numerical models (catchment, cyclonic storm tide, and tidal channel and floodplain) and application of climate change scenarios
- Assessment of potential climate change impacts
- Completion of a risk assessment
- Development and initial evaluation of adaptation options, and
- Assessment of the implementation of adaptation options versus a ‘do nothing’ approach.

Model outputs were produced for the present, 2030 and 2070 time slices using the following future sea-level rise scenarios:

- 2030: 143 mm sea level rise (IPCC emission scenario A1B, 95th percentile); and
- 2070: 700 mm sea level rise (a high emissions scenario based on the latest science).

Catchment modelling found that changes to runoff volume were approximately twice that of projected changes to rainfall on a percentage basis. The total catchment discharge varied depending on the climate change scenario. The modelling indicates that:

- From current conditions of 102 ‘dry’ days – For the 2030 scenario, the number of ‘dry’ days per year could increase or decrease by up to five days per year. For the 2070 scenario, the number of ‘dry’ days per year could increase by 18 or decrease by 13 days per year.
- From current conditions of 98 ‘wet’ days - For the 2030 scenario the number of ‘wet’ days per year could increase by seven days per year or decrease by up to nine days per year. For the 2070 scenario, the number of ‘wet’ days per year could increase by 18 or decrease by up to 34 days per year.
- Large flood events which currently last 20 days per event, for the 2030 scenario could decrease by 12 days per event or increase by 10 days per event. For the 2070 scenario, large events could remain unchanged or increase by nine days per event, indicating the potential for climate change to significantly alter the frequency, duration and extent of large floods.

Cyclonic storm tide modelling showed only minor differences to the statistical storm tide levels. In summary, results for the entrance of the South Alligator River were:

- At 2030, with a sea level rise of 143 mm, the predicted increase in storm tide was an extra 150 mm; and
- At 2070, with a sea level rise of 700 mm, the predicted increase in storm tide was an extra 100 mm. The reduced increase in storm tide at 2070 from that of 2030 projected from the modelling may be attributed to modelled variables such as increased water levels and the resultant decreased shoaling, and vegetation effects on waves, that can result in less surge.

The tidal channel and floodplain model found that sea level rises may have significant impacts because increased water levels are efficiently propagated up the river to the tidal head (landward limit of the tidal component of the South Alligator River system). Storm surge impacts were less significant, both in the degree of increase and also because they are associated with cyclones which are expected to happen about once per year. Key findings include:

- Tide heights would be increased by the sea level rise for much of the tidal channel;
- Both the existing tide and 'tide + sea level rise + surge' propagate efficiently to the upper estuary;
- Increased overtopping of river banks / natural levees; and
- Tidal propagation into the estuary is likely to result in greater pressure on the tidal head and the extension of this area towards the Yellow Water wetland.

Dendritic channels which are created by scouring or blocked by sediment from freshwater draining from the catchment will experience increased tidal pressure keeping them open longer or forcing them to extend further onto the floodplain. In addition, increased tidal flows and velocities are expected to occur which may result in tide levels overtopping river banks and/or levees. The combined effect of expansion of the dendritic channel system, together with increased levee overtopping is likely to result in increased saltwater intrusion during the dry season, and an increased likelihood of impacts to nearby freshwater billabongs.

IMPACTS ON VALUES

The environmental values of the region were identified and based on services provided by the natural environment. For example, billabongs provide refuge for many aquatic species during the dry season including species that are iconic, threatened, or bush tucker. Billabongs are also of value due to their tourism and recreational significance. Ecological responses were assessed through an evaluation of how environmental values would be affected by predicted hydrological and geomorphological changes. The potential environmental impacts extend across freshwater, estuarine/freshwater and estuarine/marine zones. Potential impacts in freshwater habitats include decreases in the extent of freshwater flora, monsoon rainforest and woodlands. Other potential impacts are decreases in abundance of pig-nosed turtle, potadramous fish, freshwater crocodiles and magpie geese. For estuarine habitats the potential impacts include decreases in abundance of yellow chats, mud crabs and threadfin salmon as well as changes in the extent of mangroves (with retraction in some areas and possible expansion into other areas).

In addition, the South Alligator River was divided into key habitat zones, to allow for a specific assessment of each habitat system. Habitats included the coastal area (near the mouth of the river), the lower estuary, the upper estuary, the floodplain, and the catchment's freshwater areas. Varying likelihood and severity of impacts were taken into account in the assessment of habitat zones.

IMPACTS ON VEGETATION COMMUNITIES

The tolerance of vegetation species to different inundation and salinity regimes determines the distribution and extent of various wetland communities, and ultimately their sensitivity to sea level rise impacts.

Woodlands and rainforests, for example, are infrequently inundated and have very low salinity tolerances. They are therefore unlikely to persist in areas even infrequently inundated by saltwater. Furthermore, these communities are intolerant of long-term or continuous immersion and are therefore unlikely to persist in areas where increased rainfall results in water-logged soils.

While Melaleuca forests are seasonally inundated by freshwater for a period of up to several months each year, saltwater inundation is typically catastrophic for Melaleucas due to their high sensitivity to salinity. Indeed, previous saltwater intrusion events in the nearby Mary River have led to extensive Melaleuca dieback.

Mangroves are tolerant of cyclic, short-term inundation (i.e. diurnal tides) and high salinities but are intolerant of long-term immersion (i.e. measured in days to months). Similarly, saltmarsh communities are tolerant of short-term inundation and high salinities, but are generally only inundated during very high tides.

Cultural and socio-economic impacts were assessed on the basis of modelling results, understanding of cultural importance, location of values, and potential sensitivities to predicted changes. The analysis considered results from a desktop review of previous literature, and consultation with Bininj and key stakeholders. The cultural assessment specifically examined potential impacts on aspects of the following:

- living on country;
- looking after country;
- bush tucker;
- getting income from country;
- looking after special places and continuing tradition;
- language.

Impacts on cultural values were largely dependent on the impacts to species of cultural significance (e.g. bush tucker) and limitation of access to country including sites of cultural significance.

Assessment of the impacts to socio-economic values also included consideration of mining (both within and adjacent to the South Alligator River), tourism and recreational activities, employment, small business, public health, and existing infrastructure. The predominant socio-economic impact was access limitations. Access limitations include changes in the type and number of areas that can be easily accessed, or changes in the number of times it is difficult to access an important site. Built infrastructure could also be impacted by future flooding of increased frequency and intensity, resulting from a combination of sea level rise and more intense storm activity.

RISK ASSESSMENT

The risk assessment process is part of an iterative risk management process which allows continuous improvement that can easily be used by Park management within Kakadu National Park. In the context of the risk assessment, risk does not refer to the risk of climate change occurring, but refers to the risk of impact from climate change projected using the climate change scenarios for 2030 and 2070.

The severity of future risks from climate change impacts were assigned and assessed using a qualitative risk assessment. The analysis involved an initial risk assessment by the study team, the outcomes of which were documented in a ‘risk register’ that was workshopped with stakeholders and traditional owners (Bininj). The workshop process allowed for the initial risk assessment to be verified and/or amended as appropriate.

The following table describes key (high or extreme) risks to the South Alligator River region values as a result of climate change.

Table ES-1: Summary of high and extreme risks to values from climate change

RISKS TO ECOLOGICAL VALUES	2030	2070
Decrease in freshwater flora	Medium-high	High
Loss of magpie goose feeding and nesting areas	Medium-high	Extreme
Decrease in abundance of key species (freshwater crocodile, frog, barramundi, yellow chat, potodramous fish)	Medium-high	Medium-high
Decrease in monsoon rainforest extent	Medium	High
RISKS TO CULTURAL VALUES		
Road access cut to key sites	High	Extreme
Storm and water inundation damage to archaeological sites, sacred sites and outstations.	Medium-high	High
Decrease in bush tucker availability due to sea level rise	Medium-high	High-extreme
Decreased caring for country and harvesting of resources due to land degradation	Medium	High
SOCIO-ECONOMIC VALUES		
Reduced road access to mine and rehabilitation sites	Medium	High
Storm damage to general infrastructure and infrastructure at proposed mine sites	Medium	Medium-high
TOURISM		
Reduced road access to major tourism attractions	Medium	Medium-high
Saltwater intrusion damage to tourist attractions (locations and iconic species)	High	Extreme
Increased storm damage to infrastructure, damage to fish nurseries and recreational fishing, reduced jobs, and degradation from increased use of accessible areas and new areas.	Medium	High
PLANNING AND REGULATION		
Current development becoming inappropriate	Low-medium	Low-high
Increased resources for ongoing management and planning	Low-medium	Medium-high

Comprehensive information on risks to South Alligator River values is covered in Table 5-7.

ADAPTATION OPTIONS

Adaptation options and potential barriers or constraints to implementation were identified and evaluated through a workshop process. Also considered was the timescale for implementation of these options, agencies responsible for implementation, and possible partnership arrangements.

A multiple criteria analysis was undertaken to assess the performance of potential adaptation options against a 'do nothing' approach for the 2030 scenario. The different criteria included in the analysis were: cost of implementation, level of risk mitigated, efficacy, feasibility of implementation, and benefits to the regional economy. Suggested treatment options in the criteria were given equal weighting. Orders of magnitude were applied in the multi-criteria analysis and a trade-off matrix was then used to determine how each option performed in comparison to other options. The best performing adaptation options were to promote new forms of tourism (that are adaptable to potential climate change impacts) at key existing sites, maintain access to priority sites, manage crocodile numbers, and manage key ecological sites to build resilience. The following table describes the assessment of key adaptation options.

Table ES-2: Performance and priority of adaptation options

OPTION	COST	RISK LEVEL	EFFICACY	FEASIBILITY	BROADER BENEFIT	PRIORITY RANKING
Tourism						
Promote new tourism at existing sites	M	H	H	Yes	H	1
Open new sites	H	H	H	Yes	H	2
Replicate sites and/or create living museum	VH	L	Ineffective	Uncertain	L	9
Maintain access to priority sites	H	H	H	Yes	VH	1
Maintain infrastructure at priority sites	H	M	H	Yes	M	4
Manage crocodile numbers and minimise human contact	M	H	H	Yes	H	1
Maintain World Heritage listing	L	M	Neutral	Yes	H	3
Mining						
Rehabilitate past mining facilities	H	L	Poor	Uncertain	L	8
Upgrade infrastructure for proposed mines	VH	L	Neutral	Uncertain	H	6
Health and Safety						
Prevent introduction of tropical diseases	H	L	Neutral	No	M	7
Develop incident response plan	L	M	Moderate	Yes	M	3
Upgrade safety communication	L	M	Moderate	Yes	M	3
Ecology						
Educate visitors, residents and businesses	M	M	Moderate	Yes	M	4
Manage extractive uses for the Park	L	M	Poor	Yes	M	5
Manage key ecological sites to build resilience	H	H	H	Yes	VH	1
Structural protection of priority sites	VH	H	Moderate	Uncertain	H	5
Transport and Communication						
Develop alternative forms of transport into and within Park	H	H	H	Uncertain	M	4
Construct all weather road access	VH	M	H	Yes	VH	3

VH= very high; H=high; M=medium; L-low. 1=highest priority; 9=lowest priority.
Further information on adaptation options is in tables 7-3, 7-4 and 7-5.

A review of Kakadu's policy, planning and management regime concluded that the Park's regulatory and policy environment is well developed, and that the current management regime is effectively managing current challenges, including climate change. However, the key findings from this case study reinforce the serious nature of the potential climate change impacts on key Park ecosystems. The governing management document for Kakadu, the *Kakadu National Park Management Plan 2007–2014*, currently acknowledges the potential impacts climate change may have on Park values, and outlines that further research is necessary to effectively implement rehabilitation and protection measures. In light of this, and considering the key findings from the current study, several opportunities have been identified to improve future planning, management and policy responses for Kakadu, and similar coastal environments.

Table ES-3: Research options

RESEARCH OPTIONS	CRITERIA		
	COST	FEASIBILITY	USEFULNESS
Development of digital elevation models	Very High	High	Extreme
Map of critical habitat areas	Medium	High	High
Map of important cultural sites	High	High	Moderate
Upgrade Bureau of Meteorology data	Very High	Moderate	High
Undertake hydraulic modelling	High	High	Moderate
Undertake ecological response modelling	Very High	Moderate	High

1 Introduction

1.1 BACKGROUND TO THE STUDY

The Council of Australian Governments (COAG) recognised the importance of adaptation to impacts from unavoidable climate change through the National Climate Change Adaptation Framework (COAG 2007), which identified targeted strategies to build capacity to deal with climate change impacts and reduce vulnerability in key sectors and regions (Department of Climate Change and Energy Efficiency 2008). Consistent with initiatives under the Framework and the 'caring for our Coasts' policy, the Australian Government Department of Climate Change and Energy Efficiency (DCCEE) in consultation with State and Territory Governments initiated the National Coastal Risk Assessment (NCRA). The objectives of the NCRA were to assess the socio-economic impacts and consequences of climate change for Australian coastal communities and the benefits of adaptation. Six case studies across Australia were selected to demonstrate the range of issues and methods for analysis of vulnerability and adaptation responses. The identification of case studies was based on climate change variability, the significance of the systems at risk, the availability of existing data and the likely need for government intervention to ensure a timely and efficient adaptation response. Kakadu National Park in the Northern Territory was identified as one of the case studies within the NCRA (herein referred to as the 'Kakadu case study').

The Intergovernmental Panel on Climate Change (IPCC) (2007a) suggests Kakadu is one of Australia's most vulnerable, reserved natural ecosystems (depending on adaptive capacity) to climate change impacts, with serious risk to freshwater wetlands from saltwater intrusion, and subsequent changes to species and displacement of freshwater wetlands by mangroves. Citing Hare (2003), the IPCC predicts a loss of 80% of freshwater wetlands in Kakadu for a 30 cm sea level rise.

Hare (2003) reports that an increase in global mean temperature change of 1-2°C is likely to cause moderate to large losses in coastal wetlands. Kakadu is named as one of the systems most at threat, with a predicted loss of 50% of the system with a less than 2°C change. At an increase of between 2-3°C, Hare (2003) predicts that a complete loss of Kakadu is likely. In making the above predictions and assuming that a 30 cm sea level rise displaces 80% of wetlands, Hare notes that these estimates are highly uncertain, basing predictions on and sourcing Gitay *et al.* (2001). The Gitay *et al.* report (2001) cites Bayliss *et al.* (1997) and Eliot *et al.* (1999) predicting that by 2030 wetlands could be displaced, if the 2030 projected sea-level rises of 10–30 cm occurs and is associated with changes in rainfall in the catchment and tidal/storm surges cites. Bayliss *et al.* (1997) and Eliot *et al.* (1999) have provided estimates of predicted wetland loss using the best available data at the time, with Bayliss *et al.* (1997) also mapping the area at risk of salt inundation. Both these reports rightly highlight the many assumptions and limitations that make predicting such losses difficult in a data-limited environment.

1.2 SCOPE, AIMS AND OBJECTIVES OF THE STUDY

The Kakadu case study area was limited to the South Alligator River (SAR) system within the boundary of the Park (refer Figure 11). Specifically, the study focused on the wetlands and floodplains of the SAR and the extent to which they may be impacted by predictions under two future climate scenarios (refer below).

The overall aim of the study (as outlined by the DCCEE study brief) was to carry out a desktop review, including:

> *To model river system hydrodynamics to assess the risk of saltwater intrusion and extreme rainfall events on low-lying coastal wetlands of national and world heritage significance and the implications of government planning, management and policy responses.*

Rather than produce an absolute outcome or comprehensive results of predicted climate change impacts in Kakadu, the study sought to identify a process that can be used to assess similar environments. The specific study objectives were to:

- identify the key physical processes and ecological, cultural and socio-economic values of the SAR catchment;
- develop and model river system hydrodynamics with associated catchment (rainfall) and coastal (storm surge) inputs from additional modelling for existing and projected climate change under 2030 and 2070 scenarios;
- assess the potential impacts to the key physical processes and ecological, cultural and socio-economic values;
- assess the risks of projected climate change for 2030 and 2070 scenarios; and
- identify and evaluate adaptation options including the relative costs of implementing such measures against a 'do nothing' approach.

Further, the study aimed to engage with Bininj (traditional owners and relevant Aboriginal people associated with Kakadu National Park) and key stakeholders to ensure a forum for providing data, information and input into the study, and for communicating study results back to Bininj and stakeholders. The consultation process also aimed to verify key values, build capacity to understand key findings from the risk assessment process, and determine and consider the implications of adaptation options.

For the purpose of conducting the study, DCCEE provided the two scenarios and sea level rise predictions to be used. These were:

- 2030: IPCC emission scenario A1B, 95th percentile – giving a sea level rise of 143 mm; and
- 2070: a high emissions scenario based on the latest science – giving a sea level rise of 700 mm.

Rainfall scenarios were based on the percentage change figures for Darwin, as published by the IPCC (IPCC 2000; 2007b) and interpreted by CSIRO in *Climate Change in Australia* (CSIRO 2007). Also included were predictions of changes in cyclone intensity and frequency, with 2030 representing a 10% increase in intensity (only) and 2070 representing a 20% increase in intensity and 10% increase in frequency (SEA 2009).

The study specifically addressed climate change-induced impacts related to the projected rise in sea level, statistical increase in cyclone intensity and frequency (i.e. storm surge related to changes in cyclone intensity and frequency), and rainfall changes. The scope of the study did not include other climate change factors, such as temperature increase (including increase of water temperature), fire frequency or intensity.

In undertaking the current study it is acknowledged that, in the last 15 years, a large amount of scientific work on saltwater intrusion and other potential climate change impacts has been undertaken within Kakadu National Park. While this study was conducted as desktop research with no field work or ground-truthing of data, it builds on years of previous work. Computer models (catchment, coastal and river) were developed to provide information for further assessment. A consultation-based risk assessment was also undertaken to develop adaptations options and an appropriate evaluation process.

Key project deliverables included the identification of key risks, an assessment of risk levels (for ongoing review by Park managers), and identification of potential adaptation options that could be implemented. The whole process was also clearly documented. The reason for this was to ensure Park managers are able to review the process and make changes, as appropriate, to the risks or adaptation options identified. Wetlands managers across the 'Top End' will also be able to reproduce the process for the management of other wetlands.

1.3 STUDY APPROVAL AND SUPPORT

An extensive consultation and approval process was undertaken by DCCEE prior to the study to ensure stakeholders and Bininj agreed with the overall objectives of the study. Following commissioning of BMT WBM, a permit to undertake an activity on a Commonwealth Reserve (Permit Number RK716) was issued as final approval for the study. The permit was issued to DCCEE; BMT WBM operated under this permit on behalf of DCCEE.

At the outset of the study, DCCEE initiated a Steering Committee consisting of officials from the Australian Government Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC), Northern Territory agencies (Department of the Chief Minister and the Department of Natural Resources, Environment, the Arts and Sports (NRETAS)) and representatives of the Kakadu Board of Management. Initially, the Steering Committee provided approval on the methodology. Throughout the study, the Committee provided valuable input, with the assistance of technical peer reviewers. The Steering Committee also reviewed the draft report prior to finalisation.

Further support for the study was provided by a number of parties both within and external to Kakadu National Park including:

- Bininj, particularly those with an interest in the potential impacts of climate change on country;
- Parks Australia and the Parks management team; and
- Stakeholders (listed in Appendix A) identified and approved by DCCEE, BMT WBM and the Steering Committee.

This report documents the major outcomes of the Kakadu case study and has been prepared by the consultant study team consisting of BMT WBM Pty Ltd, Coastal Zone Management Pty Ltd, Melaleuca Enterprises and Jacqueline Robinson (University of Queensland), led by BMT WBM Pty Ltd and in close collaboration with DCCEE.

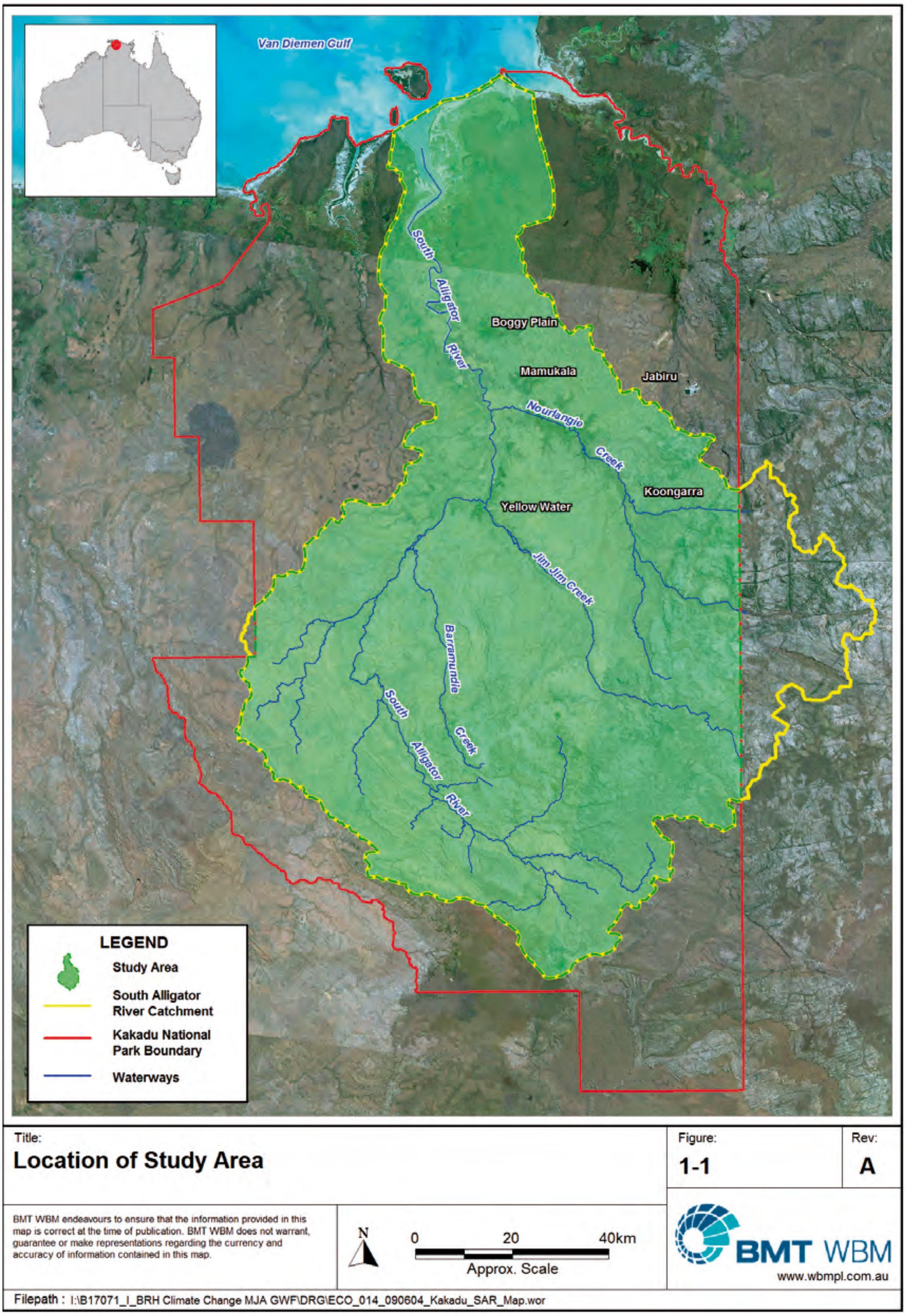

Figure 1-1: Location of study area

2 Study Approach

2.1 METHODOLOGY

In approaching the study, a six-stage process was developed and implemented, consisting of:

1. identification of key processes and values;
2. development of numerical models and application of climate change scenarios;
3. assessment of potential climate change impacts;
4. completion of a risk assessment;
5. development and initial evaluation of adaptation options; and
6. assessment of the implementation of adaptation options vs 'do nothing' approach.

Each of these stages is described in Sections 2.1.1 to 2.1.6.

This methodology was chosen to ensure a transparent process that can easily be repeated by Park managers and other wetland managers across the 'Top End'. The process provided a thorough approach to identifying the values and assessing impacts; at the same time, uncertainty in projected climate change scenarios was acknowledged through the risk assessment process, and in providing a mechanism to assess adaptation options. The process was designed to align with the vulnerability and risk assessment processes identified in Allen Consulting Group (2005) and Broadleaf Capital International and Marsden Jacobs Associates (2006) respectively. It also ensured the study stages identified above were considered. The resulting framework is shown in Figure 2-1.

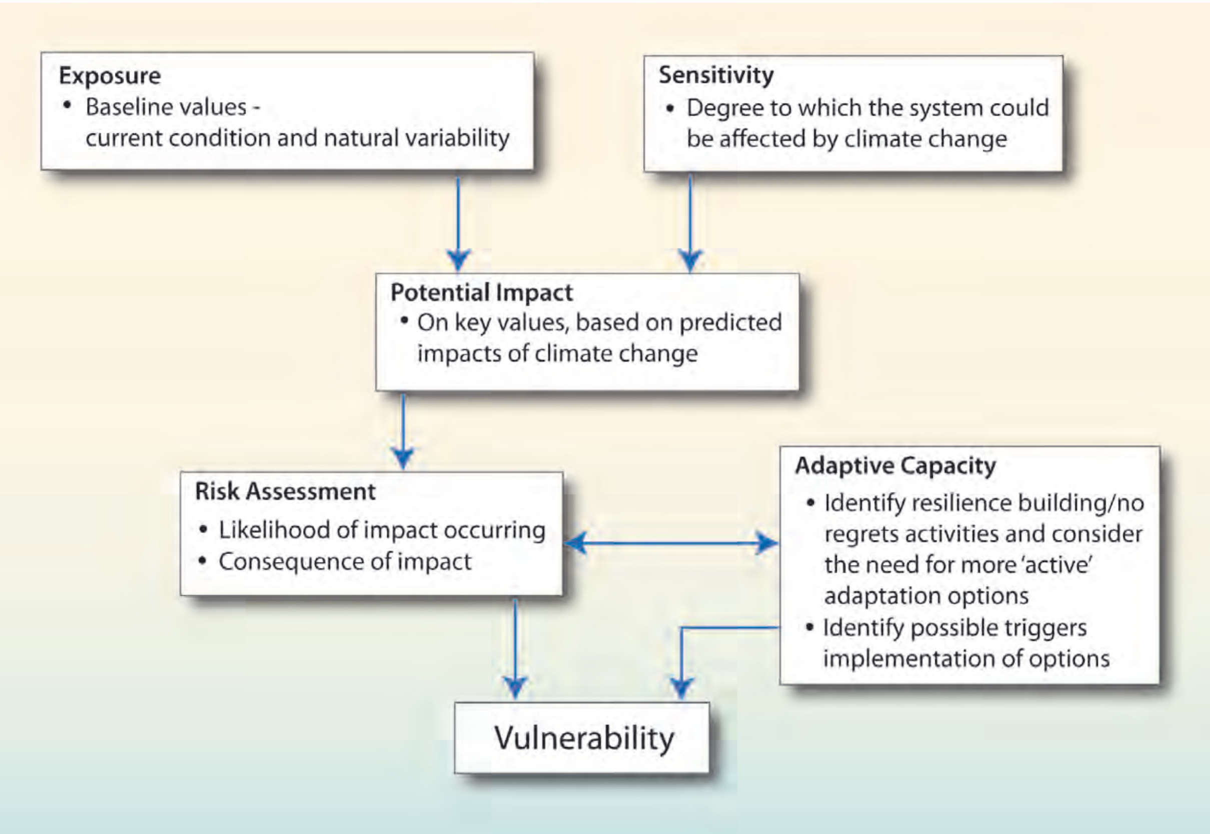

Figure 2-1: Framework for study methodology

2.1.1 IDENTIFICATION OF KEY PROCESSES AND VALUES

Through a review of existing information and available datasets, the key physical processes operating within the wetlands of the SAR were identified. These focused on processes operating over broad spatial scales that control wetland patterns and processes, most notably the interplay between tidal forcing and catchment-derived flows.

Ecological, cultural and socio-economic values were derived based on review of existing information,[1] consultation with Bininj and stakeholders (refer Section 2.2), and collaboration with other projects occurring concurrently with this study.[2] For the purposes of the ecological assessment, key environmental values (EVs) were identified. These EVs constituted habitats or species that are considered representative of key ecosystem components, processes and services within the study area. The significance of each EV was defined according to the following categories: (1) ecosystem functioning and biodiversity values; and (2) cultural and socio-economic (e.g. iconic, fisheries, bush tucker, indigenous and tourism values). The location of each EV relative to broad habitat zones (refer to Appendix D) was then identified.

Given the nature of the study, not all values and services have been identified for assessment. In this context, some species which had high values were not included either because there was insufficient life-history information to allow assessments of potential climate change impacts (e.g. critically endangered freshwater spear toothed shark *Glyphis* sp. A), or they have similar life-history characteristics to other EV species. Likewise, in some cases, cultural values or the locations of these values were unable to be identified as part of the study due to cultural sensitivities.

2.1.2 DEVELOPMENT OF NUMERICAL MODELS AND APPLICATION OF CLIMATE CHANGE SCENARIOS

The SAR floodplain, including the main river channel between Yellow Water and the coast, is the conduit through which the annual freshwater flows, which can be in excess of 3,600 GL per year, are drained from the catchment. The floodplain is extremely flat with falls of only 1-2 m over 100 km and the depressions left by historic channel alignments and settlement of previous marine deposits are filled with freshwater during the wet and evaporate during the dry.

To effectively model the transport of water within the catchment (including the floodplain and river) it was necessary to split the modelling component into distinct areas which could be independently established and calibrated. These areas were the catchment, the tidal channel and floodplain, and the tidal entrance where sea level rise, cyclones and storm surge occur.

Development of a numerical model for each area was undertaken to support the assessment of potential climate change impacts, with the climate change projections assessed limited to sea level rise, increase in cyclone intensity and frequency, and change to rainfall.

The three models developed were:

- a catchment model that was used to route existing and projected future rainfall from the upper catchment to the tidal channel and floodplain areas;
- a cyclonic storm tide model that was used to assess the existing and projected changes in storm tide levels at the coast; and
- a tidal channel and adjacent floodplain model that was used for the existing and projected future scenarios to:
  - convey freshwater from the catchment model towards the coast;
  - convey tidal water and future SLR and storm surge inland; and
  - combine all sources of water (tide, SLR, storm surge and rainfall) in an integrated model which is capable of predicting salinity and geomorphological change.

1 Information sources included refereed publications, reports, vegetation and habitat mapping, and searches of public databases.

2 For example, the CRC Sustainable Tourism Kakadu Case Study; Tremblay and Boustead (2009).

The models were developed to provide results that would indicate conditions in the wet and dry seasons with varying freshwater inflows, and an estimate of the change to levee overtopping with SLR under the climate change scenarios provided. As outlined above, DCCEE provided sea level rise projections of 143 mm and 700 mm for use in the modelling to indicate the potential differences in impacts between the following scenarios at the 2030 and 2070 timeslices:

- 2030: IPCC emission scenario A1B, 95th percentile (143 mm sea level rise); and
- 2070: a high emissions scenario based on the latest science developed by DCCEE (700 mm sea level rise).

Rainfall scenarios were based on the percentage change figures for Darwin as published by the IPCC (IPCC 2000; 2007b) and interpreted by CSIRO in Climate Change in Australia (CSIRO 2007). Also included were projections for changes in cyclone intensity and frequency with 2030 being represented by a 10% increase in intensity (only) and 2070 by a 20% increase in intensity and 10% increase in frequency (SEA 2009).[3]

Model assumptions, development and calibration are provided in Appendices I, J and K. Outputs were produced for the existing and 2030 and 2070 timeslices.

2.1.3 ASSESSMENT OF POTENTIAL CLIMATE CHANGE IMPACTS

Assessment of the potential climate change impacts on the values of the SAR catchment was undertaken using the results of the numerical models, and subsequent interpretation of the potential geomorphological change and ecological response.

Geomorphological change was inferred from results gained from the modelling (velocity and salinity changes), published material and discussions with other modellers with experience in the region.[4]

Ecological response was determined through an assessment of the potential sensitivity and likely response of the EVs to impacts from sea level rise, increased storm surge from more intense and frequent cyclones and changes to rainfall. This assessment of ecological responses was achieved by an evaluation of how the underlying physical processes (hydrological, hydrodynamic and geomorphological) would be impacted by the climate change scenarios. This assessment process also incorporated an estimation of alteration to habitat extent (i.e. the estimated proportion of the habitat potentially impacted). Potential quantitative approaches such as ecological modelling were not possible primarily due to data limitations (discussed in further detail in Section 2.3). Factors that were not incorporated in the modelling such as fire and temperature were not considered in the ecological assessment in detail, but were noted in the assessment where appropriate.

Cultural and socio-economic impacts were assessed on the basis of results from the modelling, an understanding of cultural importance and (in some cases) location of values, and potential sensitivities to predicted changes.

2.1.4 RISK ASSESSMENT

Risk assessment is a commonly understood phrase that is used to describe the approach to assessing an issue, in this case, potential climate change impacts. However, within the overall framework of risk management, for example AS/NZS 4360:2004, the term risk assessment has a specific meaning that applies to three specific steps in the risk management framework, namely: risk identification, risk analysis and risk evaluation. Risk management is an iterative process of risk assessment (identifying risks, and undertaking analysis and evaluation) and finally, treatment of the risks. Given the inter-changeability of ‘risk management’ and ‘risk assessment’ in everyday language, it was deemed appropriate for the project team to also use the two terms interchangeably. This was particularly important to reduce communication barriers with key stakeholders.

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3 The report recommended use of a 10% increase in frequency by 2070. This was identified as a worst case scenario and was subsequently used as the conditions for the modelling.

4 For example, Professor Bob Wasson (Deputy Vice-Chancellor - Research, Charles Darwin University).

The risk assessment for this project required an understanding of the risks that climate change poses and the relative significance of each of those risks. Ideally, risk assessments should be undertaken in a stakeholder-driven environment to allow risks to be identified against specific management objectives, termed 'success criteria' in the risk management framework. The risk assessment process outlined for use in this study was designed on this basis.

The risk assessment process undertaken was based on the process identified in AS/NZ 4360, and applied in a climate change context based on the report *Climate Change Impacts and Risk Management: A Guide for Businesses and Government* (Broadleaf Capital International and Marsden Jacobs Associates 2006). Firstly the risk was identified from the key potential impacts determined in the previous stage of the study. The analysis of each risk was undertaken by review of controls and management regimes currently in place to address each risk followed by analysis of the risk according to its consequence and likelihood.

The final step in the risk assessment process (risk evaluation), usually includes the screening out of risks that are judged to be relatively unimportant, eliminating them from further consideration. However, in this study, workshop participants stressed the importance of addressing all risks in the risk treatment phase in order to consider a wide range of adaptation options.

The risk assessment was undertaken in two stages; an initial risk assessment by the study team for presentation at a workshop with Bininj and stakeholders, and the risk assessment undertaken by the workshop participants that allowed for verification or amendment of the initial risk assessment.

Further detail on the approach of the risk assessment is outlined in Section 5.

2.1.5 DEVELOPMENT AND INITIAL EVALUATION OF ADAPTATION OPTIONS

In accordance with the risk management framework (AS/NZS 4360:2004), the formulation and implementation of appropriate adaptation (or risk treatment) options is required (Broadleaf Capital International and Marsden Jacobs Associates 2006). Based on reviews of existing information and consultation with Bininj and key stakeholders, an initial list of adaptation options was determined by the study team. During the workshop, participants identified additional adaptation options and identified the appropriate options to treat each of the risks. Evaluation of each of the options was then undertaken to determine potential barriers or constraints to implementation and to identify appropriate implementing and partnering agencies.

2.1.6 ASSESSMENT OF IMPLEMENTATION OF ADAPTATION OPTIONS VS 'DO NOTHING' APPROACH

As the final step in the study approach, a multiple criteria analysis was undertaken to assess the performance of proposed adaptation options identified in Section 2.1.5 against the 'do nothing' approach. Criteria such as cost of implementation, level of risk mitigated, efficacy, feasibility to implement and benefits to regional economy were identified to enable the measurement of the performance of options.

Qualitative information was used to score the performance of options against the criteria, as data to accurately estimate the performance of each option was not available for the study, and instead orders of magnitude were applied to the assessment. A trade-off matrix was then used to determine how each option performed in comparison to other options. Following conversion of the trade-off matrix to a ranking matrix, options were prioritised based on their aggregate score.

2.2 CONSULTATION

During the course of this study, Bininj and key stakeholders were engaged and consulted through a variety of methods including a workshop, meetings, presentations with discussions, interviews (phone or face-to-face) or through written correspondence (letters and emails). A list of the stakeholders approved by DCCEE and the Steering Committee is provided in Appendix A.

The two main stages for consultation were:

1. Initial consultation (February 2009): this focused on providing stakeholders with information regarding the study, and also provided BMT WBM an opportunity to seek information and further appropriate stakeholder contacts. This initial consultation focused on those Bininj identified on the Land Interest Reference,[5] but also involved consultation with Parks management staff, NT Government, and other key stakeholders. The main consultation method employed during this stage was face-to-face meetings, however where stakeholders were unable to meet with the study team, email and/or telephone contact was employed as necessary.
2. Risk Assessment and Adaptation Options Workshop (April 2009): The risk assessment and adaptation workshop was used to present preliminary findings from the modelling and impact assessment stages of the study, and as an expert/stakeholder elicitation process to jointly determine and assess the risks and adaptation options available. Group and partner sessions were used to provide focused forums for discussion of the various issues. A list of workshop participants is provided in Appendix B. Where Bininj and other key stakeholders were unable to attend the workshop, face-to-face meetings were held to discuss and assess the risks and adaptation options. Written correspondence (email and letters) and telephone was also used for provision of further information between the stakeholders and the study team following the workshop.

A brief report on the consultation with Bininj is included in Appendix C.

2.3 ASSUMPTIONS AND LIMITATIONS

As recognised by many prior studies (e.g. Bayliss *et al.* 1997; Eliot *et al.* 1999), baseline data for Kakadu is limited. The following sections outline the assumptions used and limitations encountered in undertaking the study.

2.3.1 NUMERICAL MODELLING

The basis of numerical modelling is to use local data in tested numerical formulations of the major physical processes to simulate the prototype (real) process which is often more complex. This process is legitimised by calibrating or comparing the developed model to recorded field data. The accuracy of numerical modelling is therefore closely related to the numerical description of the physical processes and the accuracy of the input data. For this study, the catchment model, tidal channel and adjacent floodplain model, and cyclonic storm tide model were able to be calibrated to such an extent that there can be confidence in the ability of the models to accurately predict changes rather than absolute values. Unfortunately, the lack of sufficiently accurate elevation data for the floodplain has meant that this has been inferred from less reliable data (aerial photography, satellite altimetry and a small amount of published data). Therefore, the results derived for the floodplain are qualitative and model results provide only a broad indication of possible changes.

As outlined above, the tidal/floodplain model is also capable of predicting morphological changes induced by the changes in flows (velocity) and the changes in carrying capacity due to salinity (flocculation). However, this modelling requires a large volume of data on sediment types both in the beds of channels and delivered from the catchment. These data were not available.

In interpreting the model results, it was assumed that the natural levee building process that occurs along the banks of the SAR is not able to respond quickly enough to SLR and the levee growth will lag behind SLR.

2.3.2 ECOLOGY

Although some vegetation communities have been mapped (e.g. Melaleuca communities), there is generally a lack of detailed habitat and vegetation community mapping and spatially-referenced ecological data available for the study area.

5 Identified on the Land Interest Reference (LIR). This was completed by the Northern Land Council (NLC) who provided the LIR to Parks staff, and study team members liaised with Parks staff to organise contact with relevant individuals and clans.

While specific or quantitative information on the environmental requirements and physiological tolerances exists for some EVs, detailed information is limited for a large proportion of the EVs.

The hydraulic modelling data is limited to the channel, and consequently this data is not applicable to terrestrial EVs and has limited applicability to semi-aquatic EVs that rely on terrestrial environments for certain stages of their life and/or for certain activities.

A number of software packages are available that allow numerical models of habitats and/or species to be constructed (e.g. STELLA, CLIMEX). While such an approach would be highly informative in determining impacts of climate change on habitats and species distributions over time, these simulations require a number of data inputs. Datasets that are required for model parameterisation may include species tolerance limits, spatial environmental data, quantitative population data and/or accurate demographic rates (e.g. fecundity, survival, migration and mortality). Consequently, due to the paucity of such data, a numerical modelling approach was not feasible for the ecological component of the study.

2.3.3 CULTURAL COMPONENTS

While a large amount of information was gathered during this study on the cultural values of the SAR catchment and observations of Bininj of changes occurring within the catchment, the study was limited by a number of factors:

- The number of people that could be consulted within the scope of the study;
- The types of information, relevance to the study and level of detail held by each person involved in consultation;
- The ability for information to be provided or reproduced spatially (specifically, this limited the ability to identify specific locations where cultural values might be impacted by climate change); and
- The level of cultural sensitivity and confidentiality required in using or reproducing the information.

2.3.4 SOCIO-ECONOMIC COMPONENTS

While information was available on the tourism and mining values of the study area, access to published material on small business or infrastructure values was limited. Information that was available to the study team was predominantly anecdotal.

3 Existing Processes and Values

This section provides a description of the key processes and values, the interactions between processes and values, and their potential sensitivities to climate change impacts. The key processes outlined within this section are the hydrological, tidal and geomorphological processes, and the key values outlined are relevant ecological, cultural and socio-economic values.

3.1 BACKGROUND

The SAR wetlands are characterised by not only a high level of diversity, but also complexity in terms of wetland functions, the processes that control these functions, and patterns in community and assemblage structure. Theses habitats occupy a complex geomorphological, climatic and hydrological setting, and are regulated by a wide variety of physical, biogeochemical and biological processes that operate over a variety of spatial and temporal scales (Figure 3-1).

The catchment comprises a diversity of habitats ranging from nearshore coastal waters through to estuarine and freshwater riverine habitats and marshes. These habitats are functionally interlinked and together act as a wetland complex rather than discrete wetland units. A diverse suite of flora species comprise these habitats, often with distinct wet and dry season plant communities (Finlayson *et al.* 1988, 1990). Large populations of birds, fish, reptiles, frogs and invertebrates inhabit the wetlands, with some taxa displaying seasonal migration between permanent and temporarily-inundated habitats. While there is a reasonably sound understanding of the ecology of some of the better known ‘charismatic’ species, such as saltwater crocodile and barramundi, for the vast majority of species, important life-history characteristics and the controls on these features are poorly understood.

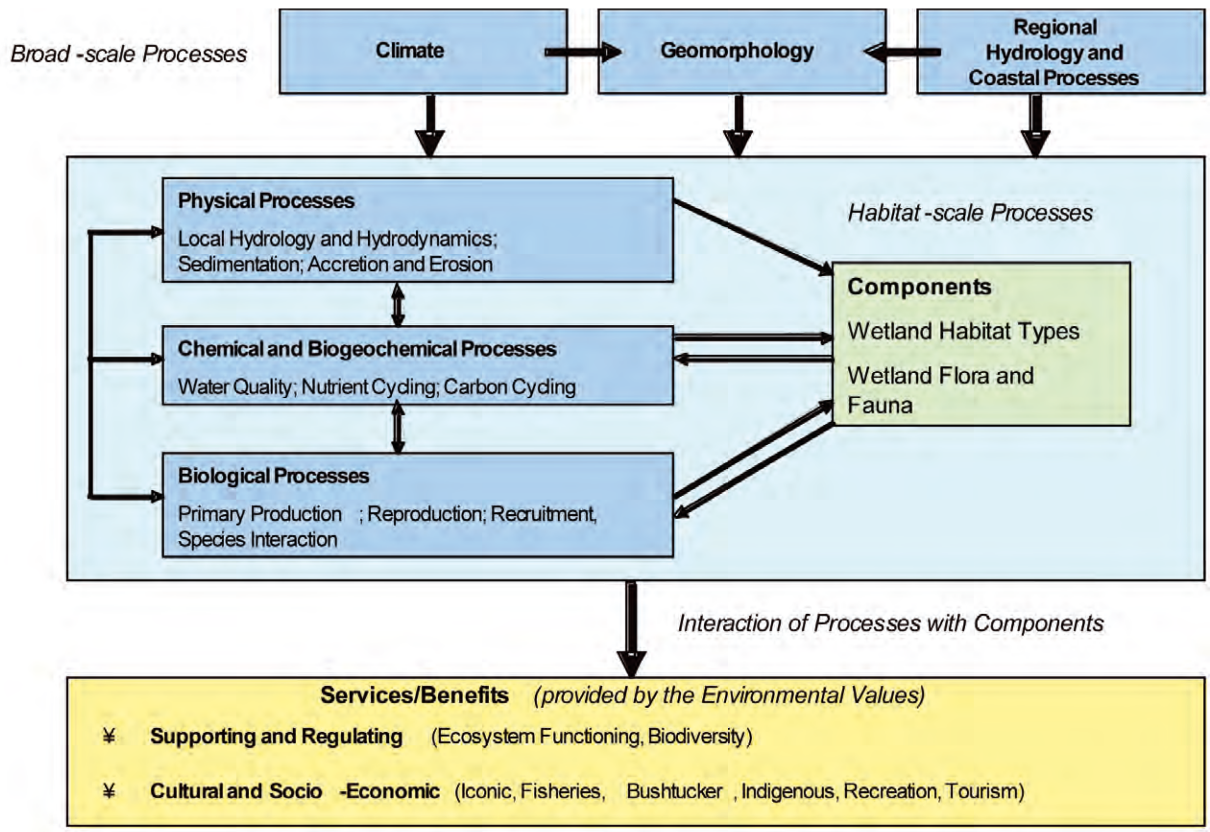

Figure 3-1: Conceptual model showing interactions between key physical drivers within SAR wetlands

Cultural values of the catchment are in part based on the ecological values and also on the culture of the Bininj of the SAR catchment and surrounding area. Tourism and other socio-economic values are also intrinsically linked to the above values.

3.2 KEY PHYSICAL PROCESSES

The SAR is located in the monsoonal zone of Northern Australia (refer Figure 1-1) and experiences the resulting extremes of the annual wet/dry cycle. The SAR has experienced dramatic processes since the region stabilised in its current state about 1300 years ago. A broad description of the historical processes as well as the existing physical drivers is described in the following sections.

3.2.1 HISTORICAL CONTEXT

There have been three major geomorphologic phases in the tidal interface region within the recent Holocene (Hope *et al.* 1985, Woodroffe *et al.* 1985). Extensive mangrove swamps developed along the present inland extent of the South Alligator Valley approximately 6500 – 7000 before present (BP), when a post-glacial rise in sea level caused the then dry South Alligator Valley to flood with saltwater.

Over time, sediments from tidal deposition led to the filling up of the river valley, and the gradual retreat of mangrove swamps towards the coast, followed with their replacement by pioneer species. The mangroves initially extended 90 km upstream but were probably largely restricted to their present location along the coast by 5500 BP (Woodroffe *et al.* 1985).

The transition between saltwater and freshwater biological systems was likely to be a highly complex process, as each system excluded the other (Clark and Guppy 1988). It is likely that hyper-saline flats formed along many of the inland tidal channels by 3000 BP. As freshwater from wet season floods flowed through the hyper-saline region, the soil salinity gradually declined until sedges and grasses became common. However, the vegetation of these freshwater floodplains was and still is dependent upon continual renewal from seasonal freshwater.

Although the process of progradation, tidal deposition and levee establishment continues to this day (refer Section 3.2.5), it is likely that the current balance of freshwater floodplains and tidal drainages stabilised by approximately 1300 BP (Clark and Guppy 1988, Woodroffe *et al.* 1989). This balance is maintained by the interaction between the deposition of tidal mud in the dry season and the scouring of tidal mud from wet season flood waters (Petty *et al.* 2005). However, the system is highly dynamic, and significant channel changes have occurred in the past, as evidenced by the presence of several paleochannel systems that run almost parallel to the present channel in the tidal transition region.

3.2.2 OVERVIEW OF CURRENT PHYSICAL PROCESSES

The freshwater flow from the SAR and Jim Jim Creek discharge into the Yellow Water wetland that then drains into a mangrove lined tidal channel which extends approximately 105 km to the coast. The other major freshwater input further downstream is from Nourlangie Creek (refer Figure 1-1). Within this region, tidal pressure and channel formation work to maintain both freshwater and saltwater systems in a highly dynamic balance.

The saltwater system is contained by a series of naturally built levees at approximately the high spring tide level. These levees are submerged by seaward flowing freshwater during the wet season. Freshwater scour channels in the levees as the wet subsides are overtaken by tidal waters and so called dendritic (tree like) channels are formed. These channels are relatively short (less than 1 kilometre) and are ephemeral, as the silt carried by the flood tide tends to heal the scour channel entrance.

High seasonal and inter-annual flow variability within this system results in changes in channel width and position on decadal to millennial time scales. Since the mid to late Holocene, the saltwater-freshwater boundary has changed by 80 km seaward.

Numerous studies have highlighted the dynamic equilibrium which exists between the freshwater and saltwater systems (e.g. Vertessy 1990). This is made more complex by the relatively high tidal range, high seasonal rainfall and the high natural variability in these and other physical process drivers.

The tidal interface region is very sensitive to change in the estuary and is subject to incessant channel contraction and expansion. Channel contraction occurs when tidal mud is deposited in pre-existing channels effectively blocking any further tidal ingress into the channel. Infilled channels are stabilised by the salt tolerant grasses and are later colonised by pioneering mangrove species. Channel expansion occurs late in the wet season when freshwater runoff drains from the floodplain. An inspection of aerial photographs indicated many kilometres of these blocked and stabilised channels (refer Figure 34).

In addition to containing the saltwater channel, tidally formed levees also impound freshwater in large wetlands. During the course of the dry season, the salinity of these wetlands increases, and in some areas becomes quite brackish.

3.2.3 RAINFALL AND HYDROLOGY

The catchment of the SAR extends from the coastal floodplains in the north to the sandstone plateau in the south. Rainfall across the 11,700 km^2 catchment is strongly seasonal with approximately 90% of rainfall occurring between the months of November to March each year. Average annual rainfall across the catchment shows a moderate rainfall gradient between the coast (1,400 mm/yr) and plateau (1,200 mm/yr). However, the total annual rainfall for Darwin can vary from around 750 mm to 2,000 mm (Vertessy 1990). Average annual rainfall in the SAR region has been increasing at a rate of between 30 mm and 50 mm per 10 years since 1950 (BOM 2009).[6] It should be noted here that the average annual pan evaporation is around 2,000 mm, which is significantly higher than the rainfall. Catchment runoff also follows a strongly seasonal pattern with distinctive wetting up of the catchment in the early wet season followed by large flood flows between January and March. Major streams in the catchment cease to flow for several months of the year at the end of the dry season at which time high evaporation quickly reduces the levels in ponding waterbodies.

3.2.4 TIDAL PROCESSES

The tidal component of the SAR extends from the mouth in Van Diemens Gulf to just north (downstream) of Yellow Water, a distance of about 105 km. The maximum range in the tide height at the mouth of the SAR is 5.8 m (Vertessy 1990). Comparative values for Mummarlary, Cuspate and Bridge stations are 5.6 m, 4.9 m and 5.0 m respectively, indicating that there is only minor attenuation of tidal amplitude with distance from the sea over most of the river.

The tide at the mouth is moderately asymmetric (i.e. not equal in duration) with spring tide ebb and flood durations of approximately 415 and 320 minutes and neap tide ebb and flood durations of 410 and 325 minutes. The shorter flood tide with a steeper tidal gradient is responsible for sediment transport up the river.

Near the mouth of the river, where tides display only marginal ebb/flood duration asymmetry, current velocity patterns approach symmetry. The ebb/flood duration and velocity become increasingly asymmetric with distance upstream, with flood tides having shorter durations and higher peak velocities. In the mid and upstream reaches, flood current velocities approach 2 m/s, while ebb current velocities rarely exceed 1 m/s (Vertessy 1990). Therefore, the flood tide is capable of carrying a much higher sediment load than the ebb tide.

Another major influence on water levels at the SAR mouth are storm surges induced by cyclonic winds. The absolute level of these surges can be in the order of 4 m (Vertessy 1990). However, this increase is added to the exiting tide level at the time of the cyclone to give a combined storm tide level. This level is not necessarily above the HAT level for the river because of the random nature of the combination of tide and surge.

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6 The cause of the increase in annual average rainfall is uncertain, however anthropogenic aerosols have been highlighted as one of the possible causes of this phenomenon (Rotstayn et al. 2008).

Lastly, with regard to salinity, it has been documented (Vertessy 1990) that the flows experienced during the wet are sufficient to flush the tidal channel to freshwater levels over almost the full length of the estuary.

3.2.5 GEOMORPHOLOGICAL PROCESSES

Published reports have indicated that tidal rivers in the Northern Territory have several morphological phases (Chappell and Woodroffe 1986; Woodroffe *et al.* 1986). The rivers move from one phase to another as they respond to tidal pressure and seasonal freshwater runoff. Different longitudinal regions of a river will show distinct morphological features depending on the state of development of the particular region. Figure 3-2 and Figure 3-3 show typical cross sections in the lower and upper part of the SAR tidal estuary.

As tidal force decreases upstream, tidal silts are deposited in levees which then contain saltwater flow within the river banks. These levees generally form at peak spring tide level. The velocity of the incoming tide is much greater than the force of the water that drains out of the floodplain after a high tide event. Therefore, the incoming water is capable of carrying a much higher sediment load than the outgoing water. This sediment is deposited along tidal channels, gradually forming a mud levee that prevents further saltwater penetration (Petty *et al.* 2005).

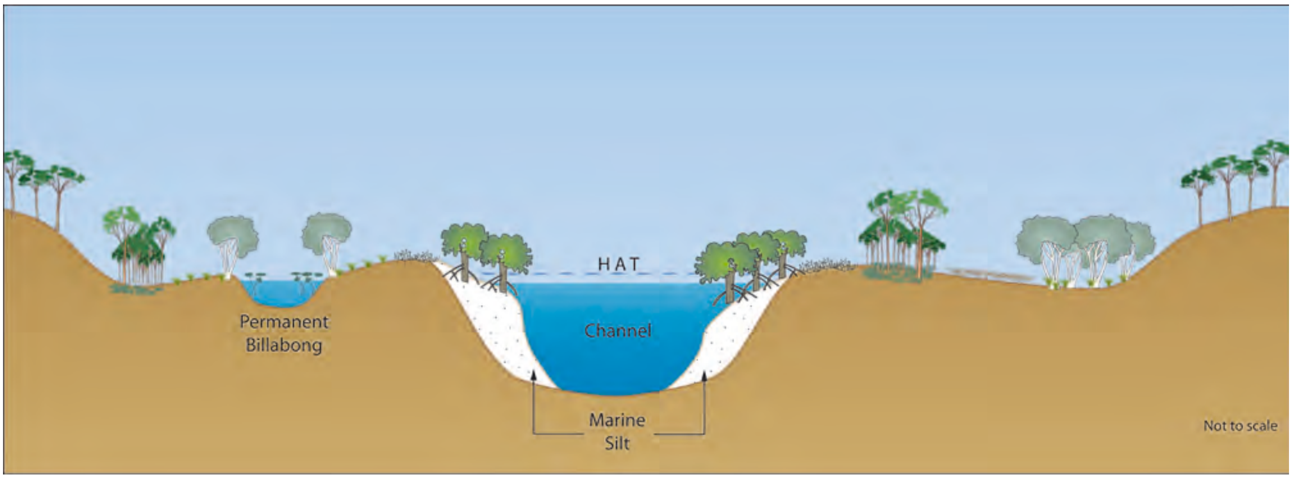

Figure 3-2: Typical cross section of lower estuary

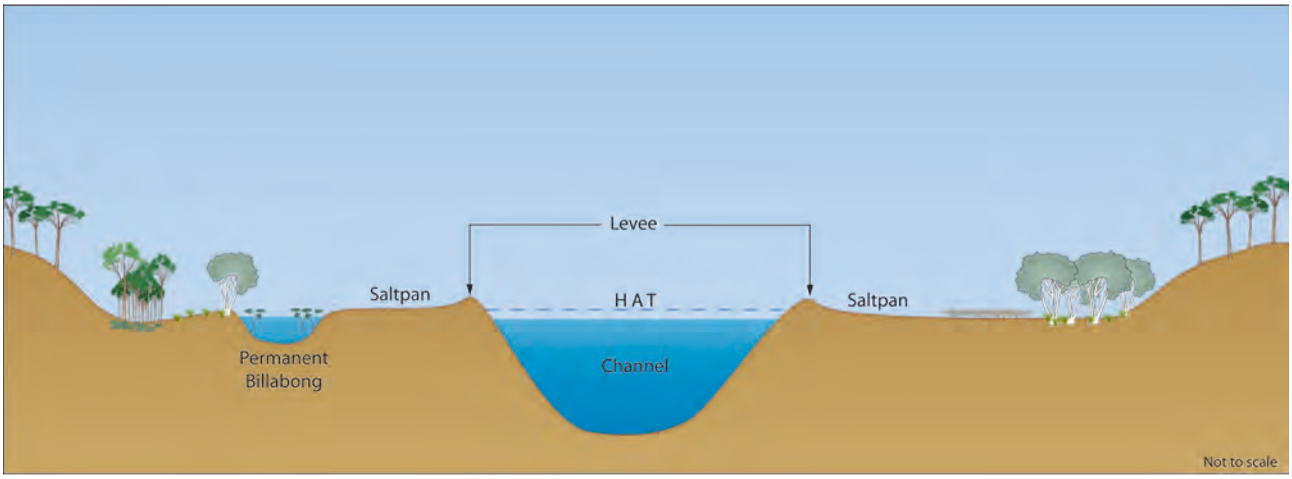

Figure 3-3: Typical cross section of upper estuary

In addition to containing the saltwater within the channel, the natural, tidally formed levees also impound freshwater in the adjacent wetlands. During the course of the dry season, the salinity of these wetlands will increase, and in some areas will become quite brackish.

Channels established across levees have the potential to accelerate drainage of the wetlands. Because of the historical evolution of the region, the wetlands soil often overlays a highly saline subsoil region. Annual freshwater impoundment maintains the low salinity soil surface. Without impoundment, subsoil salt may emerge and cause widespread die-off of freshwater species.

Figure 3-4 shows the tidal head region of the SAR immediately downstream of Yellow Water. This aerial photograph mosaic clearly depicts the features formed in recent times (i.e. in the last several thousand years) and the resulting dynamic equilibrium which exists. These features are described below, are marked on Figure 3-4 and include paleochannels, dendritic (ephemeral tree-like channels) and billabongs which generally form in paleochannels.

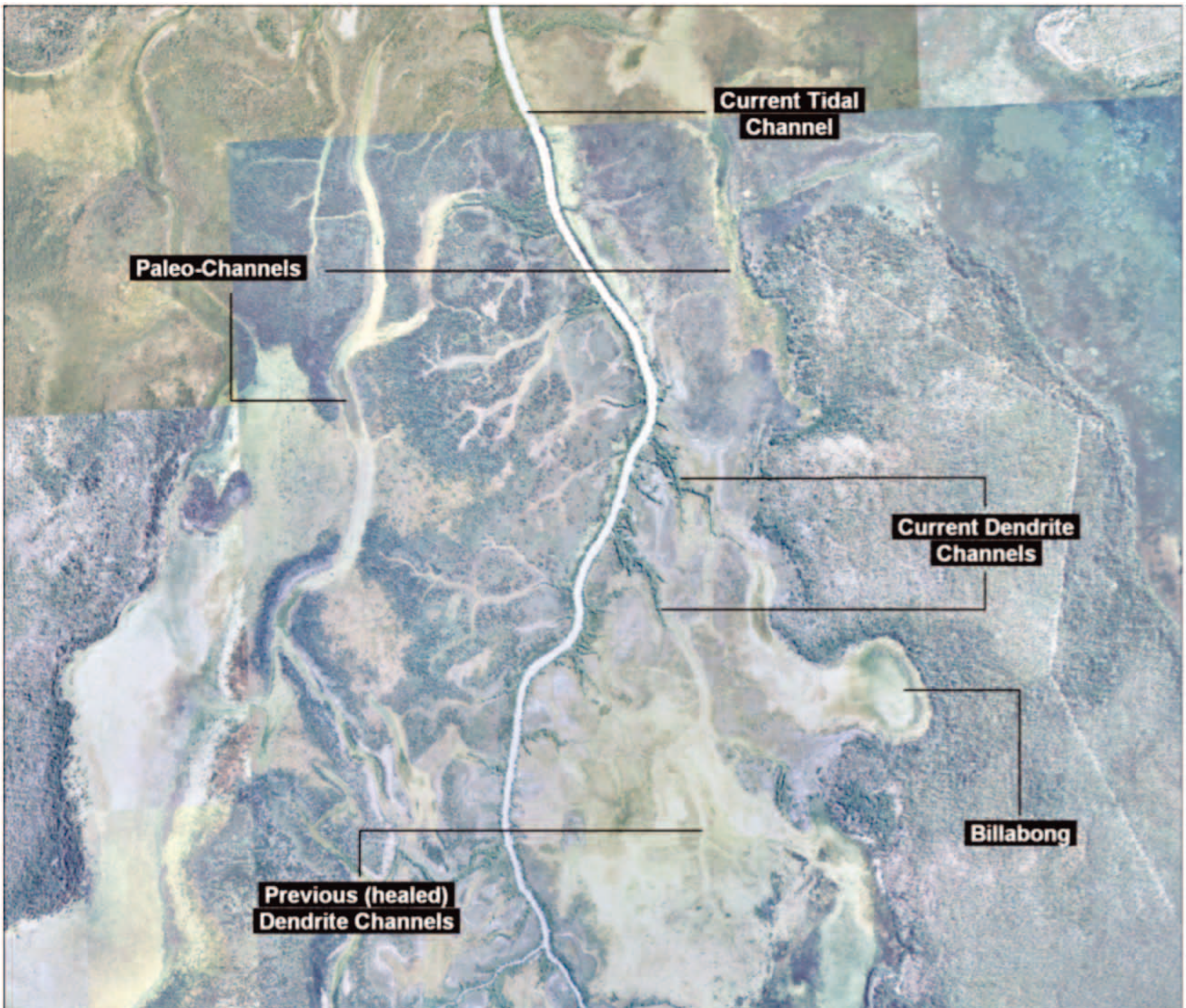

Figure 3-4: Aerial photo of tidal head area showing paleochannels and dendritic channels

Geographical Elevation

Maximum elevations of the coastal floodplain of the SAR are less than five metres, and commonly close to the spring high tide level of approximately three metres above mean sea level. Substantial regions of the coastal plains are at elevations below this (Wasson 1992, Woodroffe and Mulrennan 1993). Many of the remote backwater plains lie at or below the elevation reached by the highest tides, yet are protected from tidal inundation by the slightly higher elevation of levees that lie adjacent to the river channels (Knighton *et al.* 1991). The low gradient of the coastal and estuarine floodplains of the northern coast, with a seaward gradient of as little as 0.5 m to over 70 km, emphasises the degree to which they are vulnerable to invading saltwater by either levee scour or dendritic channels. Because the levees prevent natural flow back to the tidal channel, levee overtopping increases the salinity of the adjacent floodplain.

Palaeo-channels and Dendritic Channels

Knighton *et al.* (1992) suggested that several factors have contributed to the vulnerability of floodplains to extension of tidal channels. They noted that tidal channels develop through a combination of extension and widening of the main channels as well as through tributary growth. The process of tidal channel formation reportedly begins with overbank flooding of saltwater over the floodplains during exceptionally high tides (Knighton *et al.* 1992). Wet season floodwaters act to accentuate the process of tidal scour. Almost six metre spring tides in Van Diemen Gulf allow the effects of tidal action to occur at the headwaters of the tidal channels, up to 105 km inland (Woodroffe *et al.* 1986). Furthermore, the macro-tidal range ensures there are bi-directional currents with high velocities within the tidal influence of channels and hence a high potential for tidal scouring (Knighton *et al.* 1991).

Distinct palaeochannels are recognisable adjacent to the SAR and these are remnant tidal channels that were active during the mid-Holocene, and have since been partially or completely infilled by the deposition of tidal silts and sediments (Woodroffe *et al.* 1986; Woodroffe and Mulrennan 1993). They are apparent as billabongs, freshwater swamps and wetlands, and are therefore particularly vulnerable to saltwater intrusion. As palaeo-channels are generally some of the lowest-lying topography within a coastal floodplain, they act as low-land catchments for the development of seepage zones responsible for the initiation of channels (Woodroffe and Mulrennan 1993). Subsequently, palaeochannels may be preferentially invaded by the expanding network of tidal creeks. Whilst sediment size data has generally been unconvincing in demonstrating this preferential invasion by the tidal creeks, Woodroffe and Mulrennan (1993) suggested that the alluvial deposits of palaeo-channels should be more easily eroded than soils that have developed *in situ*. Given the erodability of the deposited sediments comprising the paleochannels, they are generally associated with bordering levee banks of higher relative elevation. Subsequently, palaeochannels, once inundated, tend to confine the pattern of saltwater intrusion and form saline basins.

Expansion of bare mudflats and the headward expansion of tidal creeks into freshwater meadows and ponds may be affected by a suite of secondary variables. Saltwater intrusion results in the death of freshwater vegetation and creation of bare surfaces susceptible to Aeolian (wind blown) erosion (Rhodes 1980, 1982). During the dry season the sediment surface is smoothed by tidal flows but dries to desiccation and cracks deeply between periods of tidal inundation thus leaving the surface exposed to aeolian processes.

3.2.5.1 RECENT ANTHROPOGENIC CHANGES

Within this highly dynamic system, the process of progradation, tidal deposition and levee establishment continues today. However, in recent times the fine balance of the system of levees and channels that maintain freshwater and tidal regions has been tested by impacting agents such as buffalo and boats (Petty *et al.* 2005). Some aspects of these are described below.

Buffalo Impact

It has been reported that the large buffalo population in the mid-1900s had a devastating impact on vegetation and floodplain behaviour particularly in upper section of the tidal plains between Kapalga and Yellow Water (Petty *et al.* 2005). After the removal of buffalo in the 1970s and 1980s, it has been reported that there was a rapid re-establishment of floodplain vegetation which has been able to stabilise the soils, reduce channelisation during freshwater runoff and hence reduce the formation of dendritic tidal channels.

Boat Impact

It has also been reported (Petty *et al.* 2005) that boat traffic can create saltwater channels and these have immediate effects as the boats generally follow the direction of flow, and hence erosion is likely to develop into a channel. Erosion caused by boat propeller turbulence, particularly at shallow depths can create a channel which wet season runoff will preferentially follow resulting in scour increasing the channel size. This process is reported (Petty *et al.* 2005) to have created channels in at least three areas in the tidal interface region.

It is understood that boat usage between the upper tidal head and Yellow Water is now prohibited and the tidal disconnection between the tidal head and Yellow Water has been rebuilt naturally since this prohibition was implemented (D. Lindner 2009, pers. comm., 25 Feb.). However, the fragility of this tidal head area is an indicator of the potential for SLR to promote the SAR tidal head into the Yellow Water wetland.

Drainage of Freshwater Floodplains

The process of increased drainage of freshwater billabongs by dendritic tidal channels has been described in the literature (Skeat *et al.* 1996, Petty *et al.* 2005). It has been considered that the increased potential of dendritic channel development under changed runoff conditions is potentially more biologically significant than the expansion of saltwater channels.

3.3 KEY ECOSYSTEM COMPONENTS

Due to limitations on project scope, it was necessary to identify a variety of habitats and species that are broadly representative of some of the key ecosystems of the SAR catchment. While habitats and species represent only two ecosystem components, and other features, such as trophic functions and diversity values, deserve equal consideration. Where possible, these other functions and features have been captured in the assessment of habitats and species.

3.3.1 HABITATS

Figure 3-5 shows the extent of wetland vegetation types within the SAR catchment, which is based on broad-scale (1:1,000,000) vegetation mapping (Wilson *et al.* 1990), together with more detailed (1:100,000) mapping for mangrove (provided by Parks Australia), Melaleuca (Brocklehurst and van Kerckhof 1994) and monsoon rainforest (provided by Parks Australia) superimposed.[7] Major billabongs were digitised from 1:250,000 topographical mapping and are also displayed on the map.

In broad terms, ten functional habitat types were identified within the catchment (refer Table 3-1). These functional habitat types were categorised according to their underlying geology, together with the degree of tidal and/or freshwater inundation as determined by their location and elevation within the landscape. All but two of the habitat types (marine waters, channel environments) are characterised by a distinct vegetation community that is composed of plant species suited to the specific attributes of the particular habitat. Most habitat types are represented across two or more of the major geomorphologic units described in Section 3.2.5 (refer Table 3-1). Figure 3-6 shows a cross-sectional representation of the zonation of these communities within the study area.

Appendix D contains further information relating to the derivation of the habitat type classification system, and Appendix E describes some of the notable flora and fauna species found in each habitat type.

7 No other vegetation mapping was available at time of report preparation.

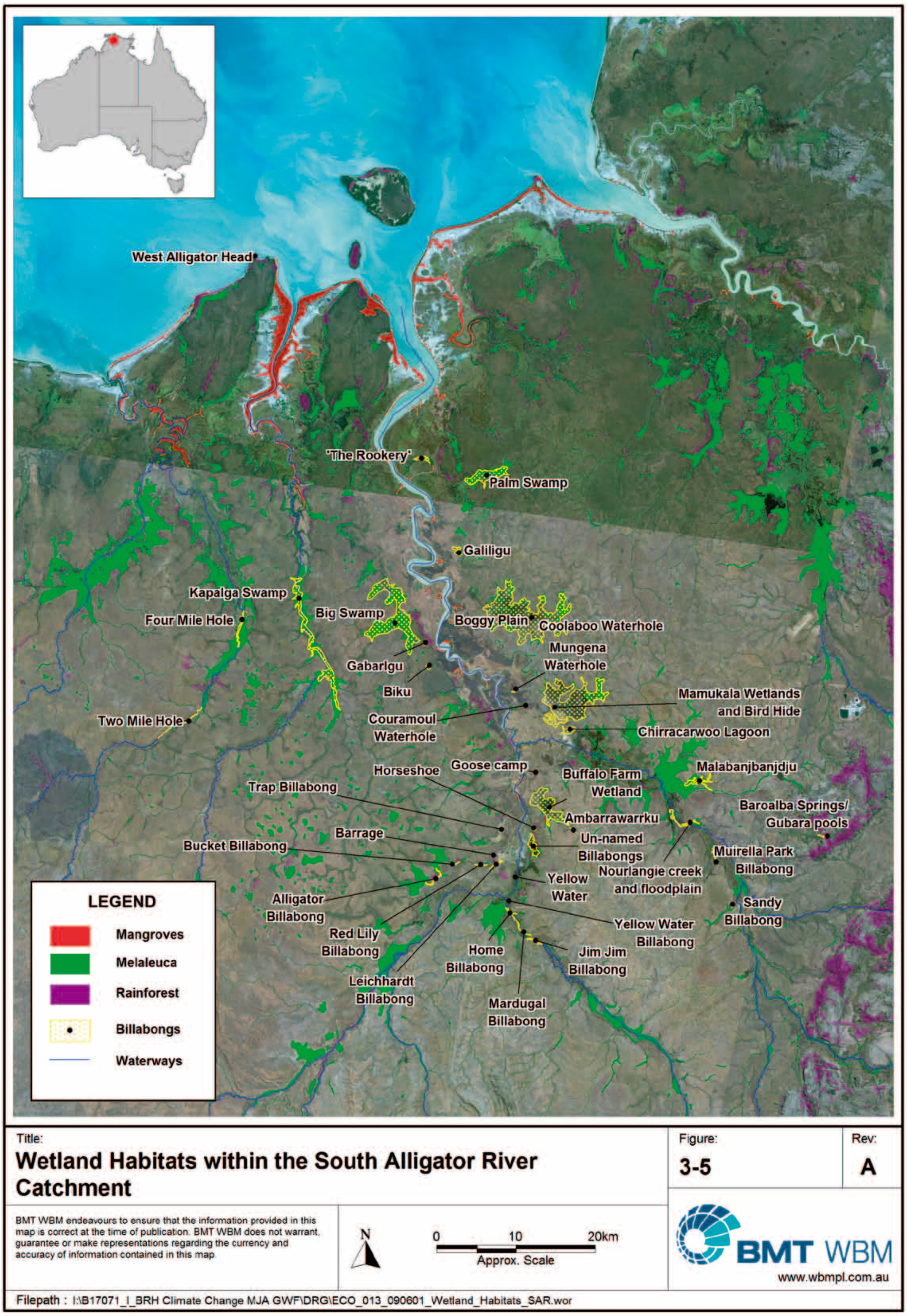

Figure 3-5: Wetland habitats within the SAR catchment

Table 3-1: Key habitat types present within the geomorphic units of the study area

HABITAT TYPE	SALINITY OF OVERLYING WATERS	GEOMORPHIC UNIT		
		COASTAL	DELTAIC	ALLUVIAL
Marine waters	Marine (<LAT)	X		
Mudflats	Marine, hyper-saline (<LAT to > HAT)	X	X	
Marine mangroves	Marine to brackish (LAT to HAT)	X	X	
Saltmarsh	Marine to brackish (>HAT)	X	X	
Channel	Marine to freshwater	X	X	X
Billabongs	Freshwater – occasional marine /brackish (>HAT)		X	X
Seasonal floodplain	Freshwater –occasional marine/ brackish (>HAT)		X	X
Fringing Melaleuca	Freshwater – occasional brackish (>HAT)		X	X
Lowland rainforest	N/A (>>HAT)		X	
Woodlands	N/A (>>HAT)			X

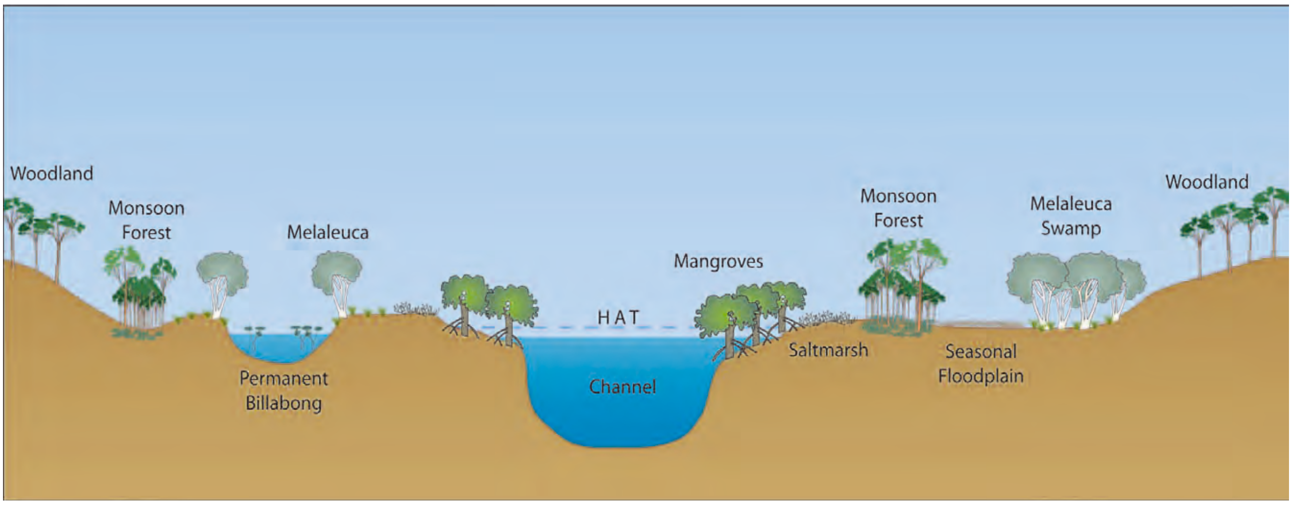

Figure 3-6: Cross-sectional profile showing relative height of key wetland habitat types in the SAR catchment

Controls on Habitats

Variations in freshwater discharge control a number of important processes in plant communities within both freshwater and marine environments. As such, the tolerance of vegetation species to different inundation and salinity regimes determines the distribution and extent of various wetland communities, and ultimately their sensitivity to sea level rise impacts. This is presented graphically in a simplified conceptual model in Figure 3-7, and discussed further below.

Woodlands and rainforests are infrequently inundated and have very low salinity tolerances (refer Figure 3-7), and are therefore unlikely to persist in areas even infrequently inundated by saltwater. Furthermore, these communities are intolerant of long-term or continuous immersion and are therefore unlikely to persist in areas where increased rainfall results in waterlogged soils.

While Melaleuca forests are seasonally inundated by freshwater for a period of up to several months each year (refer Figure 3-7), saltwater inundation is typically catastrophic for Melaleucas due to their high sensitivity to salinity. Indeed, previous saltwater intrusion events in the nearby Mary River have led to extensive Melaleuca dieback (Mulrennan and Woodroffe 1998). Seasonally inundated floodplains and billabongs are also inundated by freshwater during the wet season (refer Figure 37), but some habitats may also occasionally be tidally inundated during exceptionally high tidal events. While macrophytes such as red lotus lilies and waterlilies are highly sensitive to salinity, other species such as sedges and grasses display slightly higher salinity tolerances.

It is important to note that several freshwater wetland vegetation communities show enormous seasonal (and inter-annual) change in structure, composition and extent in response to variations in rainfall and hydrology. For example, vegetation is sparsely distributed over the floodplain during the dry season and is composed primarily of mudflat species (e.g. Coldenia procumbens, Glinus oppositifolius), whereas a multitude of plants cover the floodplains during the wet season including species such as waterlilies, sedges and grasses.

Mangroves are tolerant of cyclic, short-term inundation (i.e. diurnal tides) and high salinities (refer Figure 3-7), but are intolerant of long-term immersion (i.e. measured in days to months). Similarly, saltmarsh communities are tolerant of short-term inundation and high salinities, but are generally only inundated during very high tides.

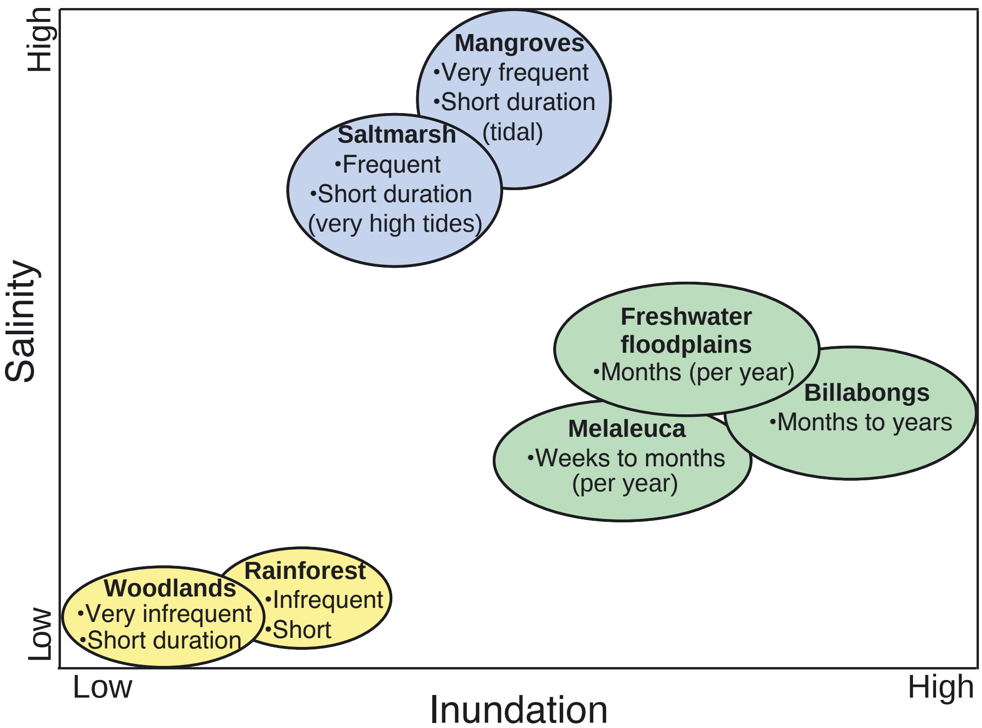

Figure 3-7: Sensitivity of vegetation communities and habitats to salinity and frequency of inundation

Based on this information, it is possible to provide some basic inferences regarding the potential sensitivity of habitats/vegetation communities to sea level rise and altered hydrology. To a large extent, the effects of sea level on the extent and structure of vegetation communities will ultimately depend on (i) direction and magnitude of change in rainfall patterns; (ii) ground level (topography); and (iii) floodplain and levee bank sedimentation rates relative to rate of sea level rise. Further detail regarding the potential responses of habitats/vegetation communities to these different processes is provided in Section 4 and Appendix G.

Note that there are numerous other physical, chemical and biological factors that control the distribution and structure of vegetation communities, many of which are directly and indirectly affected by salinity and inundation patterns. These factors may include, for example, other water quality parameters (e.g. pH, nutrients), evaporation rates and soil type. Of particular noteworthiness, native and exotic fauna may significantly influence vegetation communities, primarily through grazing and/or disturbance. The most recognised example of this is the intensive turning over of the floodplain soils by magpie geese while foraging for *Eleocharis dulcis* tubers. Fire can also have profound effects on the structure and composition of vegetation. In particular, the seasonality of fire influences the abundance and density of grasses and sedges and the survival of woody species on the floodplain (Cowie *et al.* 2000).

3.3.2 KEY ENVIRONMENTAL VALUES

A wide diversity of flora and fauna species occurs within habitats of the SAR. As discussed in Section 2.1, it is not possible or desirable to describe the specific habitat requirements of all species, or groups of ecologically similar species. Accordingly, the approach taken as part of the study was to identify a small number of species and communities that are broadly representative of the environmental values of the SAR wetlands.

The key EVs selected for this assessment are outlined in Table 3-2. The key EVs encompass representatives from each of the major habitat types, and natural (biodiversity, conservation), cultural and socio-economic environmental values. The key EVs vary in their use and dependency on wetland habitats, ranging from species that spend their entire life-cycle dependent on water (e.g. fish), to amphibious species that have partial reliance on water (e.g. crocodiles, turtles, waterbirds), and primarily terrestrial species with limited need for wetland resources (e.g. woodland plant species).

Many of the fauna EV species rely on a variety of habitat types to complete important life-history functions (refer Table 3-3). These changes in habitat use may occur between different life-history stages (e.g. juvenile, adult), or different life-history functions (e.g. spawning, feeding, roosting etc). A change (positive or negative) to habitat extent and condition therefore has the potential to influence many life-history stages and functions, varying among species (see Section 4 and Appendix F).

Appendix F discusses the values and important life history characteristics of each key EV species and community.

Table 3-2: Key Environmental Values (EV)

EVS	BROAD ECOSYSTEM FUNCTIONING	THREATENED/ MIGRATORY SPECIES	ICONIC SPECIES	FISHERIES VALUES	BUSH TUCKER VALUES	OTHER INDIGENOUS VALUES	RECREATION AND TOURISM VALUES
Freshwater							
1 Freshwater macrophytes (e.g. red lotus lilies, freshwater mangroves, water chestnut)	X		X	X	X	X	X
2 Monsoon rainforest (e.g. figs)	X				X (e.g. yams)	X (e.g. sacred sites)	
3 Woodlands (Eucalypt spp.)	X				X	X (e.g. sacred sites)	
4 Pig-nose turtle		IUCN – V Territory – NT	X		X	X	
5 Potadromous fish (rainbowfish)	X			X (food)		X	
6 Freshwater crocodile	X	IUCN – LC EPBC – Ma	X		X (eggs, meat)	X (e.g. totem)	X
7 Magpie goose		EPBC – Ma	X		X	X	X
8 Brolga		EPBC – Mi	X		X	X (e.g. totem)	X
Estuarine/Freshwater Transitional							
9 Barramundi	X		X	X	X	X	X
10 Saltwater crocodile	X	IUCN & Territory – LC EPBC – Ma/Mi	X		X (eggs, meat)	X (e.g. totem)	X
11 Yellow chat		IUCN – LC; EPBC – V; Territory - E					X – Bird watching
Estuarine/Marine							
12 Mangroves and saltmarsh	X		X	X	X	X	
13 Mud Crab			X	X	X	X	X
14 Threadfin salmon	X			X	X		X

Conservation Status: CE = critically endangered; E = endangered; V = vulnerable; NT = near threatened; LC - species of least concern; Ma = listed marine species; Mi = migratory species
Conservation Status: IUCN = IUCN Red List status; EPBC = Status under Commonwealth *EPBC Act*; Territory = Northern Territory *Parks and Wildlife Conservation Act*.

Table 3-3: Habitat types used by EV fauna species and assemblages and important life-history functions

ENVIRONMENTAL VALUE		MANGROVES	SALTMARSH/ MUDFLATS	ESTUARY CHANNEL	FRESH-WATER CHANNEL	BILLABONG	SEASONALLY INUNDATED FLOODPLAINS	LOWLAND RAIN-FOREST	WOOD-LANDS
Pig-nose turtle		-	-	-		++Breeding*, feeding, refugia	+ Feeding	-	-
Potadromous fish		-	-	+/- Juveniles	++ Breeding, feeding, spawning, refugia	++ Breeding, feeding, spawning, refugia	++ Breeding, feeding, spawning (seasonal)	+** Breeding, feeding, spawning (streams)	+** Breeding, feeding, spawning (streams)
Freshwater crocodile		-	-	-	++ Feeding, nesting*, refugia	++ Feeding, nesting*, refugia	++ Feeding, refugia	-	-
Magpie goose		-	-	-?	+ Feeding, refugia	+ Feeding, roosting, refugia	++ Feeding, nesting	-	-
Brolga		+ Feeding	+ Feeding	+ Feeding	+ Feeding	+ Feeding	++ Feeding, nesting, refugia	-	-
Barramundi		++ Spawning, recruitment, adult feeding	+ Feeding	++ Feeding, movement, refugia	++ Feeding, movement, nursery, refugia	++ Feeding, movement, nursery, refugia	++ Feeding, movement, nursery	?	?
Saltwater crocodile		Adult feeding	Feeding, basking	Adult feeding, basking, refugia	Feeding, basking, nesting*, refugia	Feeding, basking*, nesting*, refugia	Feeding, basking, nesting	?	?
Yellow chat		-	Feeding, nesting	-	-	-	Feeding, nesting	-	-
Mud crab		Feeding, recruitment, nursery	Feeding, recruitment, nursery	Feeding, nursery	-	-	-	-	-
Threadfin salmon		Feeding, recruitment, nursery	Feeding, recruitment, nursery	Feeding, nursery	-	-	-	-	-

* banks; ** streams & waterholes; Habitat use key: (+) positive habitat association; (-) negative habitat association (sub-optimal habitat); ? = uncertain whether habitat used

3.3.3 KEY BIOLOGICAL THREATS

Similar to the approach used to identify EVs, a subset of weeds and feral animals has been considered as being the most noteworthy in the context of future climate change impacts.

3.3.3.1 WEEDS

Weeds present a major biological threat, primarily due to their ability to outcompete native plants, leading to displacement of food sources for fauna as well as bush tucker species. Additionally, weeds may change the structure of vegetation communities, thereby altering habitat suitability.

While no highly aggressive weeds invade monsoon rainforest (Russell-Smith and Bowman 1992) or mangroves and saltmarsh (Bayliss *et al.* 1997), weeds are problematic within the freshwater habitats of the SAR. Two highly invasive Weeds of National Significance (Thorp and Lynch 2000) occur within the floodplains and billabongs of Kakadu National Park, namely, *Mimosa pigra* and *Salvinia molesta*. However, successful weed management within the Park has largely contained or managed to minimise the impacts of these species on native flora and fauna (refer Section 3.6.3.4).

Threats posed by exotic pasture grasses continue to increase. In particular, predicted spread of Para Grass (*Urochloa mutica*) will cause a range of negative impacts on freshwater wetlands including almost total displacement of native vegetation (Douglas *et al.* 2002). New outbreaks of another Weed of National Significance, namely Olive Hymenachne (*Hymenachne amplexicaulis*) are also notable, similarly displacing native floodplain vegetation.

3.3.3.2 FERAL ANIMALS

Feral animals have the ability to significantly damage the natural and cultural values of Kakadu National Park. Particularly notable feral animal species within the study area include buffalo, pigs and cane toads.

Feral buffalo have had considerable impacts on freshwater floodplains, tidal flats and monsoon forests in the past, but eradication programs have successfully controlled numbers of buffalo within the Park. Feral pigs have similar habitat degradation impacts, and their presence remains prevalent within floodplain and monsoon rainforest habitats.

Cane Toads *Bufo marinus* are a relatively recent arrival in Kakadu National Park, first recorded in 2001 (van Dam et al. 2002). Cane Toads have since become well-established, and are likely to colonise every habitat type present. Major impacts include reduction of food supply for native fauna, as well as fatality for toad predators due to their toxicity. In particular, declines have been noted in quolls and goannas. In turn, the availability of bush tucker may be reduced. There is currently no known method of Cane Toad control over large spatial areas (Director of National Parks 2007).

3.4 CULTURAL VALUES

3.4.1 BACKGROUND

Kakadu is home to the world's oldest living culture. Bininj[8] live in Kakadu and continue to undertake cultural practices, follow customary law and uphold tradition. Maintaining a connection to land is vital to upholding the cultural values of Kakadu, and the maintenance of living culture in Kakadu is dependent on Bininj living and travelling across their country and undertaking activities such as collecting bush tucker, land management, passing on oral knowledge and speaking in Aboriginal language. Furthermore, within Kakadu can be found perhaps 60,000 years accumulation of archaeological material cultural resources and internationally significant rock art (Brockwell *et al.* 1995). The Kakadu landscape is overlain by a complex spiritual and social system sustained by the Bininj of the land.

8 'Bininj' is used to refer to traditional owners and relevant Aboriginal people associated with Kakadu National Park.

3.4.2 WORLD HERITAGE

The United Nations Educational, Scientific and Cultural Organization seeks to encourage the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity. The World Heritage List includes 878 properties forming part of the cultural and natural heritage which the World Heritage Committee considers as having outstanding universal value. Kakadu National Park is one of these properties (UNESCO World Heritage Centre 2009).

Kakadu is inscribed on the World Heritage List under two cultural and three natural criteria. Kakadu is considered to be 'rare, if not unique, in the world' for its cultural attributes (Director of National Parks 2007). The cultural sites and traditions of Kakadu have lead to it being listed as World Heritage under the following cultural criteria:

- represent a unique artistic achievement, a masterpiece of creative genius; and
- be directly or tangibly associated with events or with ideas or beliefs of outstanding universal significance.

The archaeological remains, rock art and influence that Bininj have had on the landscape over thousands of years are also recognised in the natural criteria for which Kakadu was listed as a World Heritage Area. The SAR catchment encompasses cultural sites and traditions that underpin these cultural and natural World Heritage criteria.

3.4.3 LIVING ON COUNTRY

Kakadu provides a traditional homeland for many Bininj, with approximately 300 Bininj living within the Park (Press *et. al.* 1995). Around ten outstations are located within the SAR catchment. Bininj also live at the South Alligator, Jim Jim and Mary River Ranger Stations (refer Figure 3-8). Bininj also regularly access the SAR catchment from their residences in and around Jabiru, Arnhem Land, Pine Creek, Katherine, and Darwin and surrounds.

3.4.4 LOOKING AFTER COUNTRY

> *'Country... is a nourishing terrain. Country is a place that gives and receives life. Not just imagined or represented, it is lived in and lived with.' (Rose 1996, p.7)*

Approximately half of Kakadu is Bininj land whilst the remainder is land under claim. Bininj decided to lease their land to the Director of National Parks in order for it to be managed as a national park. A joint management arrangement enables Bininj to look after their country in cooperation with Kakadu National Park staff. Joint management is defined as 'Aboriginal landowners and Parks Australia working together and deciding what should be done to manage the Park with and on behalf of traditional owners and for other interests' in the Kakadu Management Plan 2007–2014 (Director of National Parks 2007). This provides Bininj with opportunities to be consulted, make decisions and implement these in the management of Kakadu National Park.

Kakadu's Bininj hold a substantial body of Traditional Ecological Knowledge which is defined as: *'cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment'* (Berkes 1993 in Berkes et al. 1995). The extensive time-series of observations held by indigenous societies on particular local and regional ecosystems provides a long-term knowledge base (Reid *et al.* 1992, Berkes *et al.* 1995). Traditional Ecological Knowledge is the body of knowledge which includes fire management, knowledge of plants, animals and ecosystems, ecological processes, landscape change, weather, seasons and more. Traditional Ecological Knowledge can be applied through land management practices.

Bininj engage in land management through employment as rangers, business enterprises or through traditional land management practices. Approximately 20% of the staff employed through Kakadu National Park are Bininj with a connection to Kakadu or the region (S. Winderlich 2009, pers. comm., 4 Feb.). The Aboriginal Wetland Burning in Kakadu project, jointly run through a family of traditional owners, CSIRO and the Bushfires Cooperative Research Centre, provides an example of combining Traditional Ecological Knowledge with Western science to enhance the biodiversity and cultural values of the Boggy Plain Wetland (CSIRO 2007). Such practices help to maintain the 'living culture' of Kakadu.

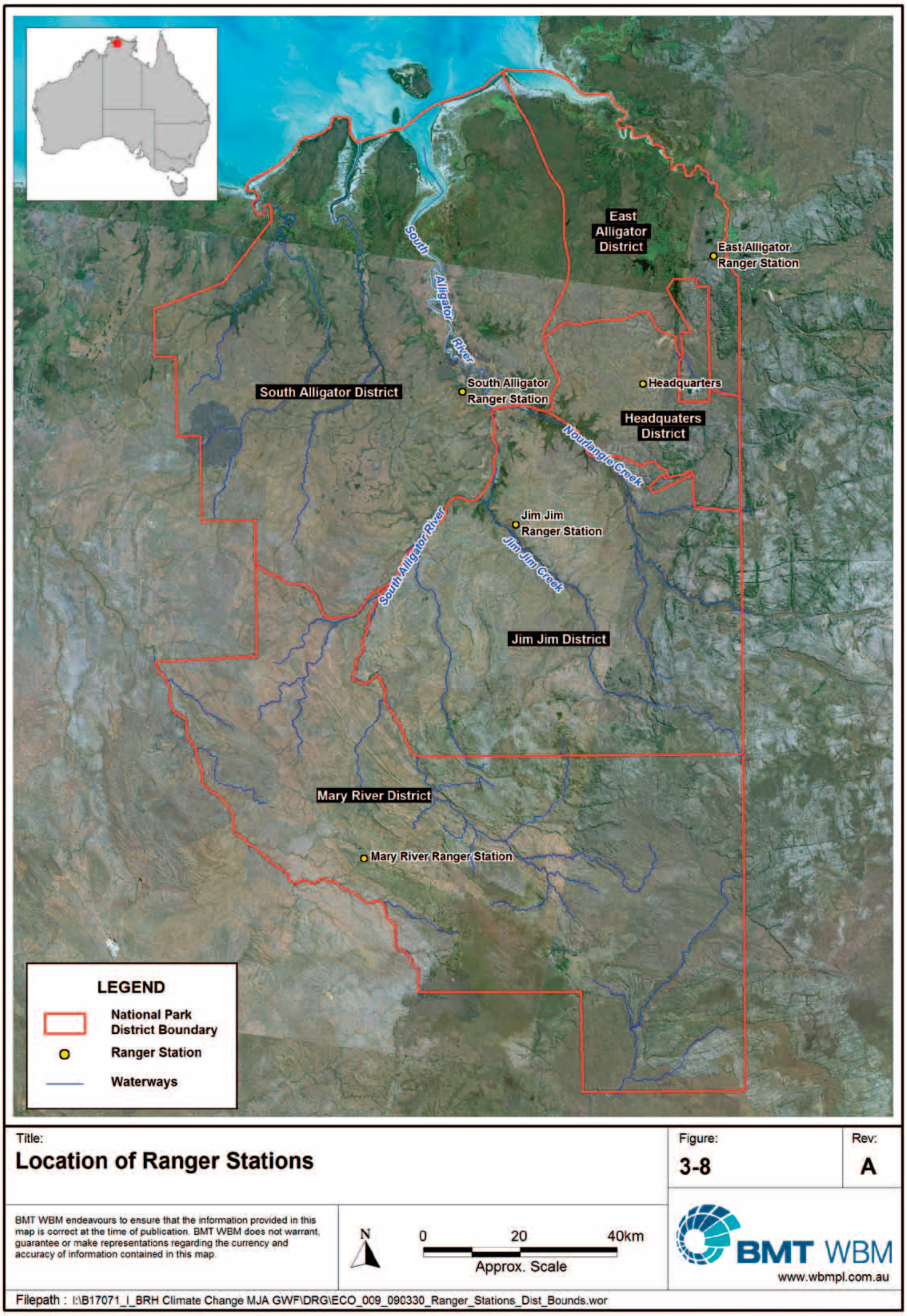

Figure 3-8: Location of ranger stations

3.4.5 BUSH TUCKER

It is estimated that Bininj have occupied the Alligator Rivers region for up to 60,000 years. When the first Europeans arrived in the area, it was predicted that the Bininj population of Kakadu was about 2,000 (Press *et. al.* 1995). Archaeological research undertaken in the wetlands of the SAR south of Nourlangie Creek estimated that 600–900 people foraged around these swamps prior to European contact (Meehan *et al.* 1985). Keen (1980) suggested that the Bininj population density in the Alligator Rivers area prior to European contact was as high as any in Australia, due to the very high productive capacity of the freshwater wetlands (Jones 1985). Explorer Ludwig Leichhardt, whilst travelling through Kakadu in 1844, described the local Aboriginal people as 'well made, active, generally well-looking, with an intelligent countenance... *They were the stoutest and fattest men we had met'* (Flannery 1998). Leichhardt also described traditional hunting of magpie geese and some varieties of bush tucker that his party shared with the local Aboriginal groups, including the heart of the cabbage palm and what could be assumed to be the Eleocharis chestnut.

The SAR catchment continues to provide abundant resources and Bininj use of these resources following traditional customs continues today. Resources may be used for food, art and craft, medicine and other customary uses (Director of National Parks 2007). Whilst Bininj diets may have changed since colonisation to include introduced foods, many traditional food resources are still sourced from the catchment with many significant hunting and fishing areas located within the SAR catchment. Lucas and Russell-Smith (1993) identified magpie geese as one of the most important avifaunal staples in traditional diet, which was confirmed through the consultation where Bininj and Park rangers identified that magpie geese meat and eggs are a highly valued form of bush tucker. During the late dry season, it is estimated that 60–70% of the total magpie geese population of the Northern Territory congregate in the Boggy Plain-Nourlangie Creek wetlands of the SAR floodplain (Bayliss *et al.* 1997). Table 3-4 (from Bayliss *et al.* 1997) lists the native animal and plant species commonly used by Bininj in the SAR floodplain, billabong and riverine habitats.

Table 3-4: Native animal and plant species in the Bininj diet (from Bayliss *et al.* 1997)

BINNINJ (GUNDJEYHMI) NAME	SCIENTIFIC NAME	HABITAT	BALANDA NAME	SEASONS AVAILABLE (6 SEASON CALENDAR)*
PLANT SPECIES				
Fruit and seeds				
Maardjakalang	*Nymphaea macrosperma*	Floodplain	Water lily	4
Yalgei	*Nymphaea pubescens*	Floodplain	Water lily	4
Andem	*Nymphaea violacea*	Floodplain	Water lily	4
Yams				
Gaamain	*Amorphophallus paeonifolius*	Lowland jungle		2
Anbidjoh/Angodjbang	*Aponogeton elongatus*	Creeks/springs		1
Angindjek	*Dioscorea bulbifer*	Jungle	Round yam	4
Angaiyawol/Gorrbada	*Diocorea transversa*	Jungle	Long yam	6
Angulaidj	*Eleocharis dulcis*	Floodplain	Spike rush	3
Galaarum	*Eleocharis sp.*	Floodplain	Spike rush	4
Anburrei	*Ipomea sp.*	Sandstone		5
Wurrumaning	*Nelumbo nucifera*	Floodplain	Lotus/red lily	2
Maardjakalang	*Nymphaea macrosperma*	Floodplain	Water lily	5
Yalgei	*Nymphaea pubescens*	Floodplain	Water lily	5
Andem	*Nymphaea violacea*	Floodplain	Water lily	5

BINNINJ (GUNDJEYHMI) NAME	SCIENTIFIC NAME	HABITAT	BALANDA NAME	SEASONS AVAILABLE (6 SEASON CALENDAR)*
Anbuled/Buldeer/gukbam	*Triglochin procerum*	Floodplain		4
ANIMAL SPECIES				
Fish				
Anmakawarri	*Arius leptaspis*	Billabong	Salmon catfish	6
Dunbukmang	*Hephaestus fuliginosus*	Billabong	Black bream	6
Gulobirr	*Sclerpages jardini*	Billabong	Saratoga	6
Namanggorl	*Lates calcarifer*	Billabong	Barramundi	6
Reptiles				
Crocodiles				
Ginga	*Crocodylus porosus*	Billabong/river	Saltwater crocodile	1 (eggs)
Gumugen	*Crocodylus johnstoni*	Billabong	Freshwater crocodile	1 (eggs)
Lizards				
Birrnining	*Varanus indicus*	Floodplain/mang	Mangrove monitor	2
Djanai/Dalag	*Varanus panoptes*	Floodplain	Sand monitor	3
Galawan	*Varanus gouldii*	Woodland	Gould's goanna	3
Snakes				
Bolorgoh	*Lialis fuscus*	Floodplain	Water python	1
Nauwandak	*Acrochordus arafurae*	Billabong	Arafura file snake	3
Turtles				
Almangiyi	*Chelodina rugosa*	Floodplain	Long necked turtle	2
Ngardehwoh	*Elseya dentata*	Billabong	Short necked/snapping turtle	3
Warradjang	*Carettochelys insculpta*	Billabong	Pig-nosed/pitted shell turtle	2
Birds				
Bamurru	*Grus rubicundus*	Floodplain	Magpie goose	3 (meat) 2 (eggs)
Marsupials				
Gornobolo	*Macropus agilis*	Woodland	Agile wallaby (male)	2
Merlbe	*Macropus agilis*	Woodland	Agile wallaby (female)	2
Mammals				
Nangamor	*Pteropus scapulatus*	Creeks, springs, jungle	Little red flying fox	4
Nagaiyalak	*Pteropus alecto*	Creeks, springs, jungle	Black flying fox	4

Note in the above table 'Binninj (Gundjeyhmi) name' means Aboriginal name in the local Gundjeihmi language, 'Balanda name' means the name in the English language, and 'Seasons available (6 season calendar)' means the seasons recognised in the local Aboriginal season calendar which includes six seasons.

Throughout the catchment and beyond the habitats mentioned above, hundreds of species of fauna and flora are utilised as traditional food sources. While it is beyond the scope of this study to list all of these species, a number of species were raised by Bininj during consultation for the project. These species are listed below and will be discussed further in Section 4.

- File snake
- Fresh water turtle
- *Eleocharis*
- *Magpie geese*
- *Red lily*
- *Fresh water mussels*
- *Saltwater crocodiles*
- *Fresh water crocodiles*
- *Green plum*
- Black plum
- White apples
- Red apples
- Bush potato
- Eels
- Sharks
- Stingrays
- Flounder
- Mud crabs
- Goanna/water monitor
- Black duck
- Egrets
- Pig nosed turtle

3.4.6 GETTING INCOME FROM COUNTRY

Bininj in Kakadu receive income from the land through lease and park use fees, and through enterprises related to tourism, art and craft and natural resource management. Through the lease agreement established from 1991 (Kakadu and Jabiluka Aboriginal Land Trusts) and 1996 (Gunlom Aboriginal Land Trust), rent paid to the Kakadu, Jabiluka and Gunlom Aboriginal Land Trusts from the Director of National Parks totals $273,702 per annum (i.e. amount per annum at time of signing the lease). This amount is reviewed every five years. The Land Trusts also receive 38.8% of park entrance fees, camping fees, charges, penalties, fees, fines, imposts and amounts received pursuant to the grant of any estate or interest (Director of National Parks 2007).

When the park entrance fee of $16.50 was abolished in 2004, compensation was paid to traditional owners to cover the revenue previously received from fees. The park entry fee was reintroduced in 2010 at a rate of $25 for each visitor over 16 years of age. Park entry fees are expected to generate $4.5 million in net annual revenue, with $1.746 million to be paid to the Aboriginal Land Trusts (Garrett 2008).

3.4.7 LOOKING AFTER SPECIAL PLACES AND CONTINUING TRADITION

Throughout the SAR catchment, sites of cultural significance include areas that relate to the activities that took place during the creation era and the travels of the first people, significant rock art sites, occupation sites and ceremonial sites.

Bininj believe that the land as we see it today was formed through the actions of the first people, the Nayuhyunggi. The natural features reflect the journey and actions of these first people. The living essence of some of these first people remains in the land. All land is valuable under this spiritual perspective and some sites are viewed as particularly sacred or significant (Chaloupka 1993).

It is estimated that there are at least 10,000 art sites found throughout Kakadu National Park (Brockwell *et al.* 1995). Rock art sites are largely found in the escarpment and its outliers. Rock art paintings in the region have been dated to be at least 30,000 years old and some may have been in place as early as 50,000 years ago. The rock art tells a story of landscape change over thousands of years, from the pre-estuarine period through the estuarine period, freshwater period and contact period to today. The rock art of Kakadu is internationally significant for its extensiveness, antiquity, exquisite beauty, artistic excellence and the fact that it is the world's longest continuing art tradition (Chaloupka 1993). Major rock art sites open to the public in the SAR catchment include Burrunggui (Nourlangie Rock) and Nanguluwurr while sites which are not accessible to the public may occur throughout the stone country.

Archaeological material cultural resources include occupation deposits in rock shelters, quarries where stone raw material was extracted and processed, human burial sites, stone or bone arrangements, surface scatters of stone and earth and shell mounds. These resources can be found throughout the SAR catchment from open sites and rock shelters scattered across the coastal plains, valleys and escarpment (Brockwell *et al.* 1995). Meehan *et al.* (1985) estimated that a total archaeological assemblage of 25,000,000 artefacts could be found within the SAR floodplain, and she described the area's 'archaeological manifestations' as being 'phenomenal'.

Toward the headwaters of the SAR, 'Sickness Country' is a particularly culturally significant area that covers over 2,000 km^2 (Director of National Parks 2007) (refer Figure 3-9). Controlling access and maintaining these sites is very important to Bininj. The lease agreement signed between the Director of National Parks and Gunlom Aboriginal Land Trust includes a Memorandum of Understanding Regarding the Control of Aboriginal Cultural Material in Kakadu National Park, which sets out arrangements for the control of Aboriginal cultural material (Director of National Parks 2007).

3.4.8 LANGUAGE

Knowledge of Kakadu is preserved in the ancient Aboriginal languages surviving today (Morris 1996). A number of Aboriginal languages are used in Kakadu, including Gundjeihmi, Kunwinjku and Jawoyn. These languages are maintained through their everyday use in Aboriginal communities, through documentation and through using the Aboriginal language name for places in the Park, bush tucker and in interpretive material. The use of Aboriginal languages is supported and encouraged in the Kakadu National Park Management Plan (Director of National Parks 2007). The maintenance of language is recognised as an important component of protecting cultural heritage.

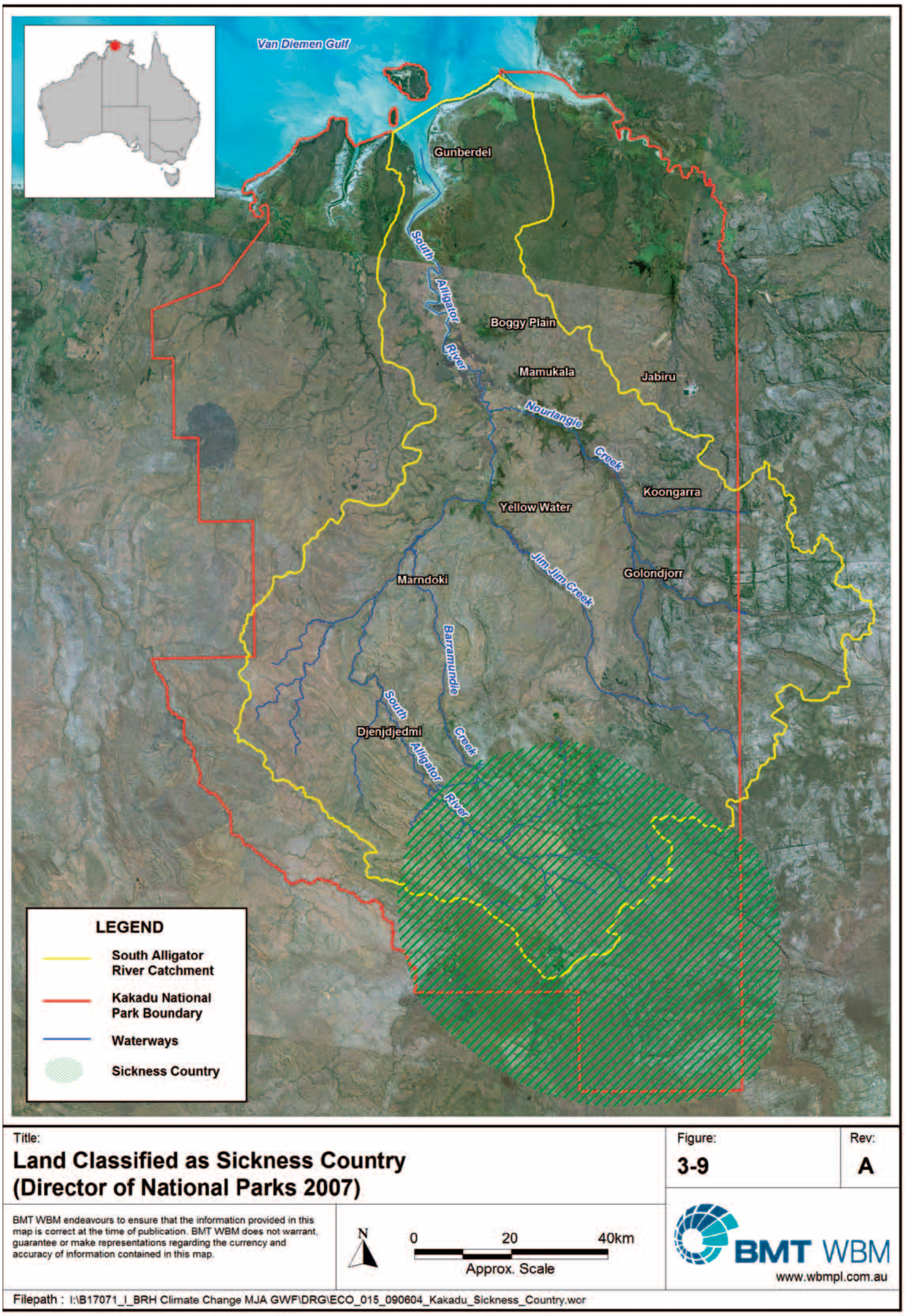

Figure 3-9: Land classified as 'Sickness Country' (Director of National Parks 2007)

3.5 SOCIO-ECONOMIC FEATURES

3.5.1 MINING

The area within Kakadu has a controversial history associated with mining. At present there are two mineral leases in the area surrounded by Kakadu National Park. These are the Ranger Mine and Jabiluka Mineral Lease. A number of disused mines are located in the South Alligator Valley, toward the headwaters of the SAR. This area was also a subject of controversy during the 1980s and 1990s when debate raged over the Coronation Hill mine at Guratba. The mining values of the area are discussed further below while the location of these features is shown in Figure 3-10.

3.5.1.1 SOUTH ALLIGATOR VALLEY

Approximately 13 former uranium mines and numerous mineral deposits are located in the upper SAR Valley. Although there are no mines currently in operation in this area, in the past it has been a highly active area with numerous deposits, many of which were mined between 1954 and 1964 (Supervising Scientist Division 2009b).

Previous mining activity has left mine shafts, tailings, old tracks and radiological contamination in some locations. Parks Australia in collaboration with key stakeholders developed the Gunlom Rehabilitation Plan, which includes two parts: covering sites with no or only minor radiological contamination; and those that have significant/ complex radiological contamination (Director of National Parks 2007). Rehabilitation is underway, with $7.4 million of funding provided by the Australian Government to clean up sites included in the Plan to an acceptable standard (Supervising Scientist Division 2009b).

3.5.1.2 RANGER URANIUM MINE

Ranger Uranium Mine is located in the East Alligator River catchment, however through social and economic factors, the SAR catchment both influences, and is influenced by, this mine. Energy Resources Australia manages the mine that is one of the largest in the world, and provides 11% of the world's supply of uranium. ERA has 519 employees, 95 of which are Indigenous. In 2008, Ranger Mine produced 5,339 tonnes of uranium. Sales revenue for 2008 was $437 million (Energy Resources of Australia 2009). Ranger Uranium Mine relies on road access from Darwin to Ranger Mine through the SAR catchment, predominantly via the Arnhem Highway, but also the Kakadu Highway. Continued access to the mine is required for transport of product from, and resources to the mine. For example, every day six trucks carrying 36,000 L of sulphuric acid per truck travel from Darwin to Ranger Mine. Two truckloads of diesel are also transported every 24 hours (D. Dettrick 2009, pers. comm., 21 April).

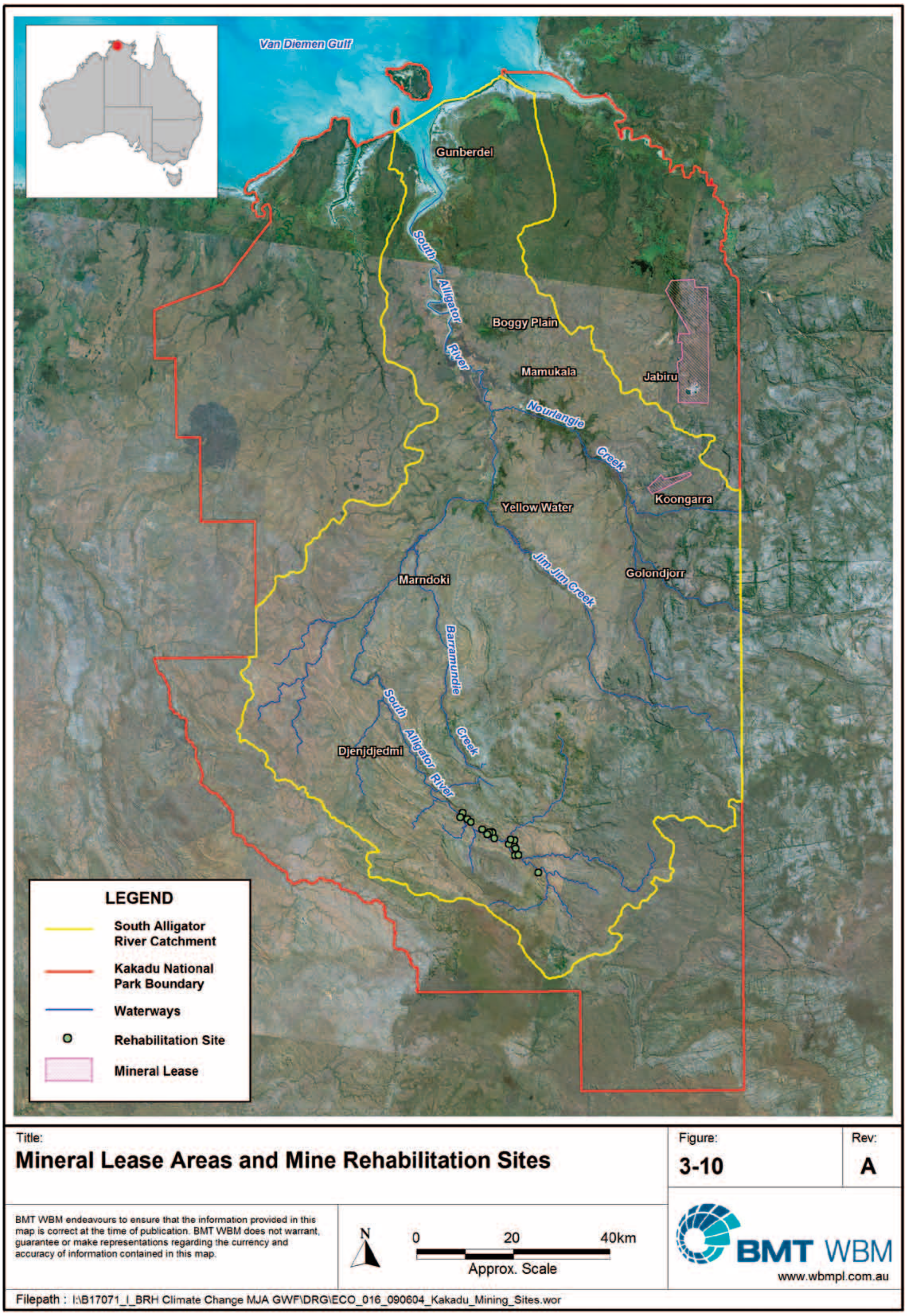

Figure 3-10: Mineral lease areas and rehabilitation sites

3.5.2 TOURISM

Tourism is a major industry in the Kakadu area and is seen by many as a sustainable mechanism for deriving income from the Park. Tourists visit Kakadu for its ancient cultural heritage, wildlife, magnificent landscapes and World Heritage listing (Director of National Parks 2007). Tourism is the fastest growing export industry in Australia and Kakadu is a major tourist attraction for overseas visitors (Kakadu Board of Management 2008). The value of the tourism industry in the Northern Territory as measured by its contribution to the NT Gross Value Added is $1.479 billion (van Ho *et al.* 2008).

The Director of National Parks states that the goal for tourism in Kakadu is that 'Kakadu National Park is universally recognised as one of the great World Heritage parks...' (Director of National Parks 2007). Furthermore, the Shared Vision for Tourism in Kakadu, according to Commonwealth of Australia (2005), is:

> *'Kakadu National Park is one of the great World Heritage Parks, recognised universally as a place with…*
>
> - *a living Aboriginal culture – home to Bininj/Mungguy;*
> - *extraordinary natural landscapes and a rich variety of plants and animals;*
> - *enriching and memorable experiences for visitors; and*
> - *a strong and successful partnership between traditional owners, governments and the tourism industry, providing world's best practice in caring for country and sustainable tourism'*

A brand strategy was recent developed for Kakadu as a *'spiritual wonder of the world'* (Commonwealth of Australia 2006). The brand strategy sought to reposition the way in which Kakadu is promoted to place greater emphasis on Kakadu as a cultural landscape, not simply as a natural landscape. Kakadu's brand positioning statement is:

> *'Kakadu is a 50,000-year-old living cultural landscape that interacts with nature and the seasons. The awesome, ancient Arnhem Escarpment frames this World Heritage wetland. It is a place with deep spiritual richness and history that inspires the senses, commands deep respect and provides self-discovery, enlightenment, adventure and relaxation' (Commonwealth of Australia 2006).*

Kakadu is a key icon destination as part of Tourism Australia's Brand Australia offering to a target market identified as the 'international experience seeker'. People, environment and lifestyle inspire the *'experience seeker'*. Kakadu could become the leading destination in Australia to deliver these experiences (Commonwealth of Australia 2006).

In 2008, 228,899 people visited Kakadu (Parks Australia North 2009). Parks Australia North estimates that Kakadu National Park contributes $100–$120 million per year to the Northern Territory economy (M. Triggs 2009, pers. comm., 4 Feb.). Tremblay (2007) conservatively suggests that a tourism contribution of approximately $15 million to the Top End region is due to the existence of Kakadu National Park.

The tourism industry is the main source of employment in the Kakadu region (Bayliss *et al.* 1997). Tourism NT estimate that direct tourism employment numbers in the Kakadu region are around 300-400 people in the peak season and around half of this during the low season (Tourism NT 2009, pers. comm., 24 Sept.). Throughout the Northern Territory, tourism consumption generated 9,682 employed positions or 9.4% of total employment during 2006–07 (van Ho *et al.* 2008). The value of Kakadu as a tourism drawcard to the Top End region is reflected in the level of NT Government and tourism industry investment in marketing the Park, which totalled $3.9 million in 2008–09 (Tourism NT 2009, pers. comm., 24 Sept.).

The SAR catchment contains major drawcards to Kakadu, including Yellow Water where 100,000 people take commercial boat cruises per year (R. Murray 2009, pers. comm., 4 Feb). Other drawcards include Twin Falls and Jim Jim Falls. In the southern end of the Park, attractions include Gunlom and Maguk billabongs where people can swim and enjoy the waterfalls.

Tourism enterprises include passive boat cruises, recreational fishing tours, cultural interpretive tours, bird watching tours, four wheel drive and waterfall tours and multi-day tours throughout the Park. In 2008, 95 tour operator permits were issued for Kakadu National Park. It can be assumed that almost all of these tour operators use the SAR catchment in some way (S. Murray 2009, pers. comm., 21 April). Many tourists also travel independently of tours.

Major infrastructure is located at Gagadju Lodge Cooinda and Aurora South Alligator Resort both of which include accommodation, restaurants, pubs and service infrastructure. Camping and day use areas are also located close to road accesses and tourist sites (refer Figure 3-11).

3.5.3 RECREATION

Recreational fishing is a popular activity in Kakadu, with 20% of the Northern Territory's recreational barramundi fishing occurring in the Park (Tremblay and Boustead 2009). Fishing occurs primarily in the estuarine zone of SAR targeting species including threadfin salmon, jewfish and golden snapper, but also through the coastal, floodplain and freshwater areas of the river. Barramundi can be fished almost the entire length of the river during the right periods of the year with the best times being during the 'run-off', when the floodwaters run off the floodplain back into the river. Saratoga and barramundi are also caught during the dry season in billabongs.

Restrictions apply on where recreational fishing can occur in the Park; no fishing is allowed upstream of the Kakadu Highway, except on Jim Jim, Muirella Park and Sandy Billabongs. Bag and size limits also apply (refer Section 3.6). Access to the river (i.e. launch sites and boat ramps) is limited for such a large catchment with high usage by fishers and anecdotal evidence suggests this encourages fishers to move up and down the river through restricted areas rather than drive the long distances to other ramps or launch sites.

3.5.4 SMALL BUSINESS

Several small businesses are based in the SAR catchment, however, most of these are tourism businesses and are covered in the tourism section. Warnbi Aboriginal Corporation works within the catchment providing outstation housing, maintenance, education and municipal services.

Resources for commercial purposes are also occasionally sourced from the catchment, for example, the collection of rainbow fish for the aquarium trade, the collection of pandanus for basket making or tree limbs for didgeridoos. The Kakadu Native Plants nursery is based in the East Alligator River catchment but collects seed from the SAR catchment.

Opportunities exist for the development of more small business enterprises in the catchment, such as natural resource management contractors but the author is not aware of any existing enterprises operating in the catchment at the time of writing.

3.5.5 BUILDINGS, INFRASTRUCTURE AND SERVICES

3.5.5.1 BUILDINGS

Buildings within the SAR catchment are used predominantly for tourism, Park management, small business and residential functions (outstations and residences of Park staff). New development within the Park must conform with and be assessed against relevant procedures and guidelines including:

- KNP Management Plan;
- environmental impact assessment guidelines (according to the appropriate category of development);
- outstations procedure; and
- Building Code of Australia.[9]

No known procedures or guidelines currently require the consideration of floor levels of proposed buildings within the catchment with regard to flood or storm surge levels. The NT Planning Scheme requires consideration of these factors but does not apply within Kakadu (an unzoned area under the Scheme).

9 Note the catchment is within 'Region C' which ensures buildings are designed to withstand a Category 4 cyclone.

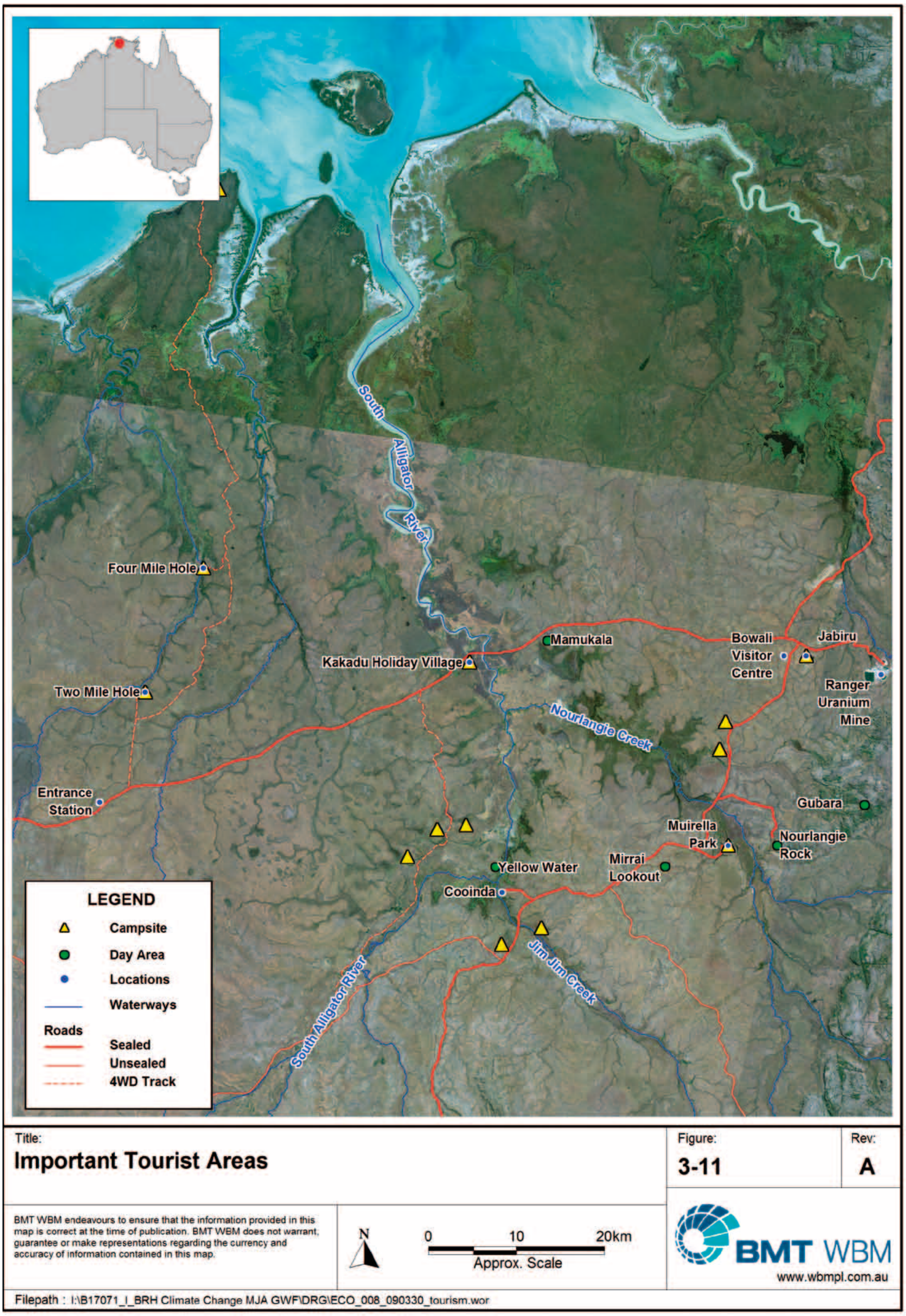

Figure 3-11: Important tourist areas

3.5.5.2 ROADS

Within the Northern Territory, roads are considered the most important of the infrastructure services, providing the link between isolated communities and the means for social and economic growth (Department of Transport and Works 1996). In particular, the roads within Kakadu are important in providing access for tourism, mining and small business purposes, as well as for access to culturally significant sites by Bininj and for management and maintenance purposes by Parks staff.

Figure 3-12 shows the designated roads within the SAR catchment. Table 3-5 identifies the purposes for which these roads are required and provides comments on existing access. Other small tracks are also present within the catchment leading to outstations and Park management facilities. Maintenance of most roads and provision of access within the SAR catchment is a joint responsibility of the Northern Territory Government and Parks Australia (refer Figure 3-12 and Table 3-5) although other organisations are also involved in and provide funding for maintenance for some roads within the catchment. In most cases, Aboriginal organisations are responsible for maintaining roads to outstations (Director of National Parks 2007). The *Local Government Regional Management Plan – Northern Region* (Department of Local Government and Housing 2008) outlines the evident lack of all-weather roads to support access to some communities within the region.

The Arnhem and Kakadu Highways are arguably the most important of all the roads in the catchment. As roads managed by Roads Networks section of the NT Government Department of Planning and Infrastructure, they are subject to annual maintenance[10] during the dry season including grading, slashing and sign replacement. Cyclic maintenance programs are also undertaken and include re-sealing (on an approximate 10–12 year cycle) and reconstruction of road shoulders. It is estimated that every 30–40 years roads may also require full reconstruction of the pavement, with bridges requiring replacement every 50–100 years.

Immunity levels for major NT roads and bridges are designed using the best available data at the time of design, including the Australian Rainfall and Runoff (AAR) guidelines, current known flood impacts, stream gauging data and hydrological assessments and projections, and are determined in relation to flood levels (mostly one in 100 year design flood event). Drivers for the construction of new roads are based on demand (e.g. community, access, tourism, mining), and standards of the road are determined relative to current and projected traffic growth, with predictions to 20 years being standard practice.

Due to constraints on access during the wet season from flooding, both the Northern Territory Government[11] and Kakadu National Park (Director of National Parks)[12] provide a road access service with regular updates on road status (whether open or closed), the date of the latest information and any other relevant information (e.g. proposed opening dates). Regular email updates are also available, and more detailed road access information is available at the Bowali Visitor Centre.

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10 Undertaken in accordance with the NT Government's *Roads and the Environment* Strategy which considers a range of environmental and social factors and the operational aspects of the road infrastructure development and management.

11 The NT Government Road Reporting website is www.roadreport.nt.gov.au. A phone service (1800 number) with a recorded message provides updated information on road conditions.

12 The Roads and Access Report for the Park is available at http://kakadu.com.au/access.

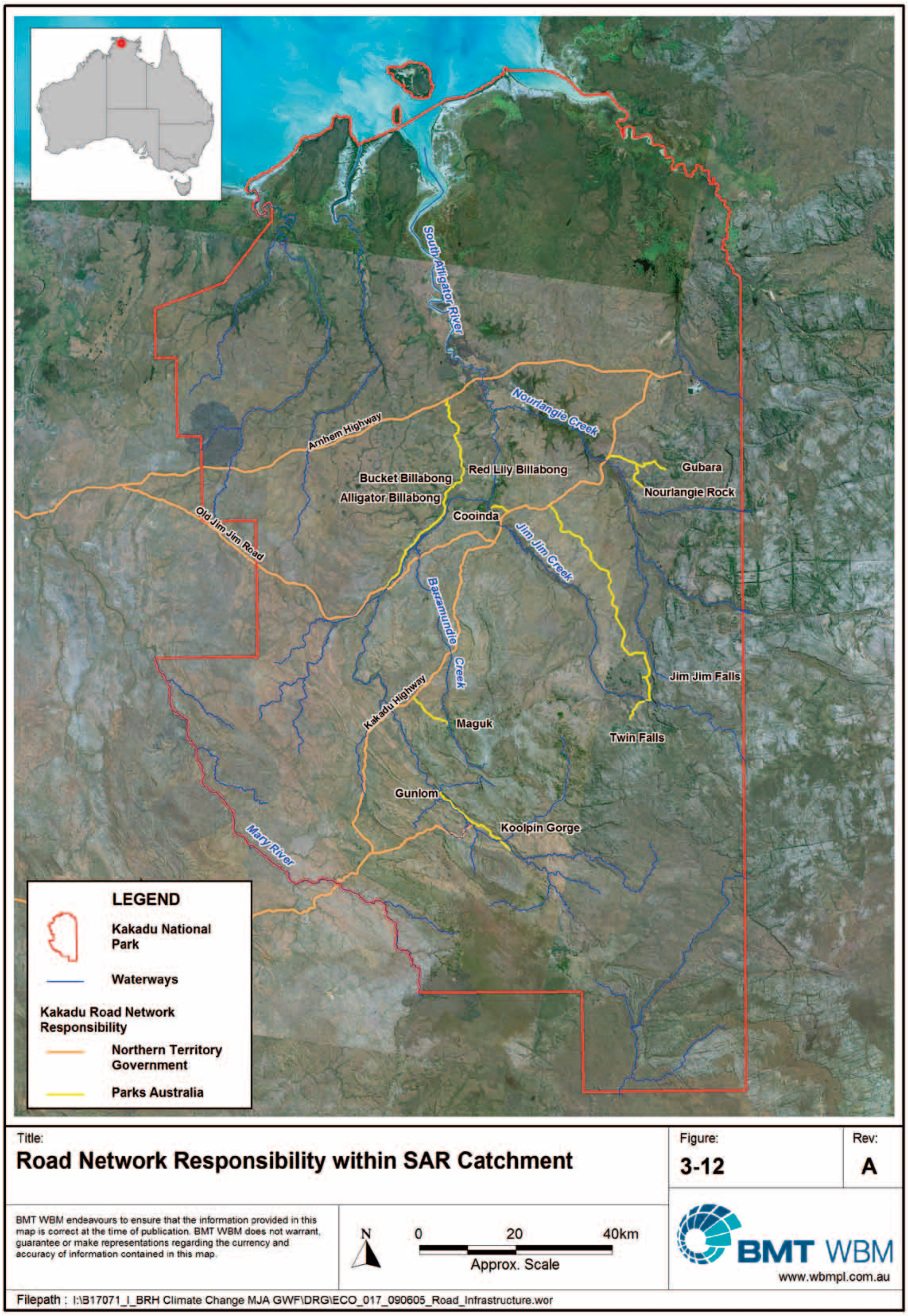

Figure 3-12: Road network responsibility

Table 3-5: Roads within the SAR catchment

ROAD NAME	RESPONSIBILITY FOR MAINTENANCE	PURPOSE FOR ACCESS	COMMENTS ON EXISTING ACCESS
Arnhem Highway	NT Government	Mining, tourism, small business, culture, Park management Access to Jabiru and Arnhem Land	Sealed road Mostly open year round Temporary closures
Kakadu Highway	NT Government	tourism, small business, culture, Park management Access to Jabiru and Mining	Sealed road Mostly open year round Temporary closures
Nourlangie Road	Parks Australia	Tourism, culture, Park management	Sealed road Mostly open year round Rarely affected by wet season flooding
Old Jim Jim Road	NT Government	Tourism, culture, Park management (partially) Access Mt Bundy Dept Defence	Unsealed road Load limit variable – dependent on conditions Only open during the dry season
Jim Jim/Twin Falls Rd	Parks Australia	Tourism, culture, Park management	4WD track Closed when flooded during wet season Road condition and visitor safety determine when re-opened
Cooinda Road	NT Government from Hwy to resort	Tourism, culture, Park management	Sealed road Open year round
Gunlom Road	Parks Australia	Tourism, culture, Park management	Unsealed road Often closed due to wet season flooding
Gimbat Road	NT Government from Hwy to Gunlom Rd turnoff, Parks Australia for remainder	Tourism, culture, Park management	Unsealed road 4WD / high clearance vehicles for part of road Often closed due to wet season flooding
Gubara Road	Parks Australia	Tourism, culture, Park management	Unsealed road Limited to vehicles under 6t 4WD access in wet season 2WD access during dry season
Road to Muguk (Barramundi Gorge)	Parks Australia	Tourism, culture, Park management	4WD track Limited to vehicles under 6t Often closed due to wet season flooding
Road to Alligator, Bucket and Red Lilly Billabongs	Parks Australia	Tourism, culture, Park management	4WD track Limited to vehicles under 6t Often closed due to wet season flooding

3.5.5.3 WATER-RELATED SERVICES

Potable water supply within the SAR catchment is sourced predominantly from bores and surface water (mostly billabongs). Rainwater tanks are also used in some locations (e.g. ranger stations). Bores within the catchment also supply the township of Jabiru (i.e. Nanambu Creek borefield), providing up to 3 ML/day and to date have not been known to run dry.

Water quality testing of the water supply is carried out on a regular basis by contractors to Parks Australia (S. Winderlich 2009, pers comm., 4 Feb.). While plenty of water is available, salinity issues occur regularly at some locations (e.g. South Alligator ranger station), and occasionally at other locations, causing issues for maintenance of Park equipment and vehicles. No groundwater studies are known to have been undertaken within the SAR to date, but anecdotal evidence suggests aquifers are sufficient to produce the volume required. It should be noted however that the aquifers are not well understood with adjacent bores reported to be providing fresh and saltwater respectively.

Sewage within the SAR catchment is mainly treated through septic systems (for Parks Australia infrastructure) which are pumped between one and four times a year dependent on the level of use. The two resorts have basic effluent systems based on a sewer pit system.[13]

No stormwater services are provided within the SAR catchment, with any runoff from developed areas being directed to nearby waterbodies.

3.5.5.4 POWER

Most power within the SAR catchment is provided by diesel generators. Power is supplied to Bowali Visitor Centre (Park Headquarters) and the Nanambu borefield by Energy Resources of Australia (ERA), while the infrastructure (power poles, lines and boxes) are provided and maintained by Powerwater.

3.5.5.5 WASTE MANAGEMENT

No waste management services are provided within the SAR catchment by Parks Australia or other agencies. Warnbi Aboriginal Corporation services the outstations within the catchment and takes waste to the Council-run landfill site in Jabiru. Parks districts and resorts within the catchment are known to use a mix of landfill and removal of certain wastes (recyclable materials) from the Park to Darwin.

3.6 RECOGNITION, PROTECTION AND MANAGEMENT OF VALUES

Values identified in the previous sections are the key to the significance of Kakadu at an international, national, regional and local perspective. These are recognised, protected and managed through a complex framework of legislation, regulation, policy, strategy and planning at all jurisdictional levels. This section examines the key components of the existing policy, management and planning framework that act to manage and protect the values of the SAR catchment.

3.6.1 RECOGNITION OF VALUES

The values of the SAR catchment within Kakadu National Park are recognised at a number of levels. At the international level the values are recognised through inscription on the World Heritage List under the World Heritage Convention under both natural and cultural criteria, and declaration as a wetland of international importance under the Ramsar Convention. Migratory species occurring within Kakadu are recognised under

13 Information provided by Park Ranger, April 2009.

international conventions and agreements; the Bonn Convention[14] and CAMBA[15], JAMBA[16] and ROKAMBA.[17,18] The wetlands of Kakadu have also been recognised through inclusion as part of a reserve network agreed to by the parties to the Ramsar Convention, the East Asian-Australasian Flyway, and as part of a Tri-National Wetlands Conservation Project operating with protected areas in Irian Jaya and Papua New Guinea.

Nationally, the cultural and natural values of Kakadu have been recognised through declaration as a national park (Commonwealth Reserve)[19] and through national level listing of its heritage values. The Alligator Rivers Region, Kakadu National Park, and other areas and places within the Park have been recognised through listing on the Register of the National Estate (refer Table 3-6 for those sites within, or partly within, the SAR catchment). Kakadu National Park is also on the National Heritage List as a place of outstanding national heritage value to the Australian nation. Native species (migratory and threatened) within Kakadu have also been recognised through listing as threatened species at the national level.

Table 3-6: Sites on the national estate register

HISTORIC	INDIGENOUS	NATURAL
Munmarlary Homestead and Surrounds	Arnhem Escarpment Sites Complex Deaf Adder Creek Sites Complex Malangangerr Sites Complex Namagon Djadjan Sites Complex Nourlangie Rock or Mount Brockman Massif	Alligator Rivers Region NT Gimbat / Goodparla Pastoral Leases (former) Jim Jim Falls Area Kakadu National Park and (former) Gimbat and Goodparla Leases Koolpin Gorge Area Rainforest Gorge Jungle Twin Falls Area UDP Falls Area Woolwonga Wildlife Sanctuary (former)

Source: listed produced using *EPBC Act* Protected Matters search, 6 June 2009.

At a regional level, Kakadu is recognised as significant for its contribution to the regional economy, particularly through tourism (refer Section 3.5.2), and the provision of recreational opportunities for Northern Territorians (Section 3.5.3). Locally, Kakadu is significant as a traditional homeland for Binnij, and a home to other local residents.

3.6.2 PROTECTION OF VALUES

Kakadu's values are currently protected by a range of legislative, regulatory and policy-based measures, which provide either (a) overarching protection of the area or species occurring within Kakadu, or (b) controls on activities that may impact on the values. The following represents a summary of the main regulatory and policy-based measures protecting the values of Kakadu.

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14 *Convention on the Conservation of Migratory Species of Wild Animals Bonn Convention*, 23 June 1979

15 *Agreement Between The Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and Their Environment*, 1988 ATS 22, Entry into force: 1 September 1988.

16 *Agreement Between The Government of Australia and the Government of Japan For The Protection of Migratory Birds and Birds in Danger of Extinction And Their Environment*, 1981 ATS 6, Entry into force: 30 April 1981.

17 *Agreement Between The Government of Australia and the Government of The Republic of Korea on the Protection of Migratory Birds*, [2007] ATS 24, entry into force 13 July 2007.

18 These bilateral migratory bird agreements are limited in their scope, do not have the power to influence migratory bird conservation across the flyway, and therefore the Australian government has encouraged migratory bird conservation through multilateral cooperation (DSEWPaC 2009).

19 Kakadu was declared a national park in a number of stages between 1979 and 1991 (under legislation that is now repealed), and recognition of the park continues under the *EPBC Act* as a Commonwealth Reserve.

3.6.2.1 PROTECTION OF AREA AND SPECIES

The protection of values recognised at international or national level is predominantly through the provisions of the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).* The *EPBC Act* provides a level of protection for Kakadu as a World Heritage property, National Heritage place and Ramsar site, and provides for the listing and protection of migratory species[20] and threatened species occurring in Kakadu. Places within Kakadu on the Register of the National Estate may also be required to be taken into account by the Environment Minster for some decisions under the *EPBC Act*, but only until 2012 when statutory protection will no on longer be afforded to the places on this Register. Recovery plans and threat abatement plans (under the *EPBC Act*) are also applicable where relevant species or threats occur within the study area.

The *EPBC Act* also provides for the protection of, and requires the preparation of a management plan for a Commonwealth Reserve, which subsequently becomes a statutory instrument after approval by the Minister. The *Kakadu National Park Management Plan 2007–2014* (KNP MP) provides for the protection and conservation of the reserve, and takes into account various matters including the interests of traditional owners and Australia's obligations under relevant international guidelines and agreements (e.g. management in accordance with the management principles for Australia IUCN Reserves, World Heritage properties and Ramsar sites outlined in the EPBC Act). Further details of the KNP MP are outlined in Section 3.6.3.

As an area under the jurisdiction of the Australian Government, legislation at the Territory level is more broadly applicable. In general, NT legislation applies to manage threats to the environment from impacts from activities (refer Section 3.6.2.2). In addition, the *Territory Parks and Wildlife Conservation Act 1976* protects threatened species within the NT and the *Fisheries Regulations and NT Recreational Fishing Controls* (Northern Territory Government 2007) conserves fish and fisheries through the establishment of possession (bag and size) limits. Parks Australia provides restrictions on fishing locations.

While the protection of Kakadu under the above regulatory framework also significantly contributes towards Australia's capability to meet objectives of national level policies such as the National Strategy for the Conservation of Australia's Biological Diversity, the National Strategy for Ecologically Sustainable Development and the Wetlands Policy of the Commonwealth Government of Australia, these policies provide no further protection of the values of the SAR catchment.

3.6.2.2 PROTECTION OF VALUES THROUGH CONTROL ON ACTIVITIES

The *EPBC Regulations* provides for the controlling of activities within a Commonwealth Reserve, providing that it should be taken into account whether a proposed activity may interfere with the protection or conservation of biodiversity or heritage or with the continuing cultural use of the reserve by the traditional owners of the land (r12.03 *EPBC Act*). Certain prohibited actions must not be undertaken within Kakadu except in accordance with the Management Plan (s354 *EPBC Act*). This includes killing, injuring or trading a member of a native species, damaging heritage, erecting a building or other structure, carrying out works, or taking an action for commercial purposes.

The *EPBC Act* requires referral of actions that will, may or are likely to have a significant impact on a matter of national environmental significance which includes Ramsar site, World Heritage properties, migratory species and threatened species. Where identified by the Australian Government as potentially causing a significant impact on one of these matters, the proposed activity is deemed a 'controlled action' and further assessment is required prior to the decision on whether the activity can proceed.

20 under BONN, CAMBA, JAMBA and ROKAMBA

The KNP MP also outlines a specific process for assessment of proposals within Kakadu. The process of assessment is based on three pre-determined categories of actions according to the degree of potential impact of the activity. Tables from the KNP MP (refer Appendix H; Director of National Parks 2007) outline the categories, impact assessment requirements, and matters for assessment. Category 1 proposals (least impact) do not require assessment, and Category 3 proposals (likely to have a significant impact) are considered to possibly require referral and assessment pursuant to the *EPBC Act*. Category 2 proposals require assessment by Park staff, the proponent or independent experts and follow a procedure (refer Appendix H) which outlines the values that are to be considered in the impact assessment.

It is worth noting that while the NT Planning Scheme (under the Northern Territory *Planning Act 1999*) applies generally to Kakadu (e.g. regarding clearing of native vegetation and subdivisions), Kakadu is within an unzoned area under the Scheme, and as such the general performance criteria (e.g. relating to land subject to flooding and storm surge) do not apply to development within Kakadu. Further, other standards such as the Building Code of Australia (2009) do not set floor levels related to flood or storm surge.[21] Other Northern Territory legislation (e.g. *Waste Management and Pollution Control Act, Water Act, Weed Management Act 2001*) applies generally to activities undertaken in Kakadu and provide some management or protection to the coastal and marine environment from activities (ALGA 2006). However, the integration between this legislation is regarded as weak and at times the use of the legislation for managing threats to the values outlined in the above Sections can be considered ineffective (NTG, LCNT and NHT 2005).

Protection of values through controls on activities is also implemented within the West Arnhem Shire, which is approximately 49,236 km^2 and covers the majority of the study area. Although relatively few local government services are delivered by the local government within the study area, values within the study area are protected from these activities through a framework set up under the Northern Region's *Local Government Regional Management Plan – Northern Region* (Department of Local Government and Housing 2008), a statutory instrument under part 3.1 of the *Local Government Act 2008*. The provision of services are noted within the Plan to be subject to the rights and interests of Indigenous traditional owners (*Aboriginal Land Rights Act (NT) 1976* and the *Native Title Act 1993*), a range of Northern Territory legislation (e.g. Control of Roads Act, Disasters Act and Weeds Management Act) and Commonwealth legislation (*EPBC Act*), ultimately providing protection to both the cultural and natural values of the study area in delivery of the services.

3.6.3 PLANNING AND MANAGEMENT FRAMEWORK

3.6.3.1 STRATEGIC PLANNING

Strategic planning the protection and conservation of biodiversity, including management of the potential impacts of climate change, has been undertaken at a territory-wide level. While the Northern Territory Government has no role in the day-to-day management of the Park, a large number of Northern Territory strategies, programs and plans provide direction on the protection of the values outlined in Sections 3.3 to 3.5. Table 3-7 outlines examples of relevant strategies and plans, and their aims.

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21 Note that the Building Code of Australia does apply to development in Kakadu. While not of relevance to the current study, it does require compliance with standards relating to cyclones and wind speeds.

Table 3-7: Examples of strategies and plans providing strategic direction on protection of SAR catchment values

STRATEGIES, PROGRAMS AND PLANS (IMPLEMENTING DEPARTMENT)	AIMS AND COMMENTS
NT Marine and Coastal Biodiversity Management Strategy (currently being undertaken by the Marine Biodiveristy Group of NRETAS)	Review existing strategic, policy and technical documents relating to the NT's coastal and marine ecosystems, habitats and species.[22] Key issues, actions, responsibilities, performance indicators and resources required for conservation management will be prioritised. Conservation and threat assessment for each coastal and marine habitat/species group will enable prioritisation of conservation management issues. Strategic, policy and technical issues and proposed actions will also be outlined
Draft Northern Territory Parks and Conservation Masterplan (NRETAS 2005)	Ensure that the biological diversity and integrity of the Territory's natural heritage remains intact. Involve both government and community, working together and sharing responsibility, to manage and conserve the natural and cultural heritage of the NT, paying particular attention to the role of parks and reserves (including Kakadu). ***Comments*** Includes designation of sites of conservation significance which aims to provide additional conservation efforts to protect biodiversity within these areas. This includes 2 sites partly within the SAR catchment: Alligator River coastal floodplains and West Arnhem plateau. Examines climate change as a threat to biodiversity conservation. Acknowledges one of the most marked predicted impacts is likely to be the 'increased penetration of saltwater influences in the northern floodplains, most of which are barely above existing sea level'. Simplest step to reduce impacts is to provide refuges. Suggests the possibility of constructing barriers to prevent damage from saltwater intrusion to the floodplains. Raises issues regarding prioritising remedial actions (such as barrages on floodplains) among a range of competing interests, including floodplain environments, fisheries, biodiversity conservation and Aboriginal use.
Integrated Natural Resource Management Plan for the Northern Territory: Sustaining our resources – people, country and enterprises (NTG, LCNT and NHT 2005)	To use and conserve the Northern Territory's natural resources[23] ***Comments*** Long term view with specific targets set for five years Has linkages with the Draft Masterplan Acknowledges the likely impacts on fisheries and biodiversity generally from climate change

Further, a number of strategies have been developed to deal specifically with climate change issues within the Northern Territory and Kakadu National Park. The Northern Territory has previously prepared a discussion paper on Northern Territory climate change issues (Northern Territory Government 2008)[24] and is currently preparing a climate change policy position. In addition, a *Kakadu National Park Climate Change Strategy 2009–2014* has been developed for the Park. The strategy identifies the preliminary adaptation, mitigation and communication strategies that Park managers and key stakeholders will need to implement to manage the consequences of climate change and reduce the carbon footprint of the Park. Management strategies aim to address five key objectives:

22 The coastline of Kakadu is considered part of the Northern Territory's marine environment.

23 This Plan does not exclude Kakadu.

24 The discussion paper focused on mitigation of emissions (e.g. renewable energy including solar) rather than adaptation to potential impacts.

- to understand the implications of climate change;
- to maximise the resilience of reserves;
- to reduce the carbon footprint of reserves;
- to work with communities, industries and stakeholders to mitigate and adapt to climate change; and
- to communicate the implications of, and management response to, climate change.

3.6.3.2 BUSINESS PLANNING

As outlined above, tourism is an extremely important component of the economy of Kakadu and the wide region. Many tourism businesses in the Northern Territory are certified, or are working towards certification under a range of national tourism accreditation programs. Accredited tourism businesses operating within the SAR catchment would potentially have the systems in place to review their operations to ensure they are able to adapt their businesses, and ensure their business are resilient, to changes in their operating environment.

3.6.3.3 MANAGEMENT WITHIN KAKADU

Management Arrangements within Kakadu

Kakadu is managed through joint management arrangements providing a means for Aboriginal landowners and Parks Australia to work together to enhance and protect Aboriginal rights and interests, look after the natural and cultural values and provide opportunities for safe enjoyment by visitors (Director of National Parks 2007). Integral to this arrangement is the need to consult with traditional owners regarding decisions or activities that may impact on the values of the Park. It is worth noting that while located within the Northern Territory, the NT Government has no role in the daily management of the Park. Due to this unique management arrangement (federally funded and joint-managed while located within the Northern Territory), Kakadu is often viewed as an ‘island’ (Commonwealth of Australia 2005).

Kakadu National Park Management Plan

The KNP MP is the key document for on-ground management and planning in the Park and the conservation of the values of the study area. The KNP MP is set out under six key result areas (KRAs) that reflect the Parks Australia Strategic Planning and Performance Assessment Framework:

- KRA 1: Natural heritage management;
- KRA 2: Cultural heritage management;
- KRA 3: Joint management;
- KRA 4: Visitor management and park use;
- KRA 5: Stakeholders and partnerships; and
- KRA 6: Business management.

Aims, policies and actions set the direction for management carried out to meet these KRAs. Annual reporting to the Australian Parliament is required on the outcomes of the KRAs in the Director of National Parks’ Annual Report.

The KNP MP also acknowledges the potential impacts climate change may have on the values of Kakadu, and outlines that further information is needed in a number of areas to be able to effectively undertake rehabilitation and protection measures. Significantly, the plan recognises that causes of climate change are beyond the management control of the Parks Australia and may have a significant impact on Park values.

The Park also has an Incident Response Plan (March 2009) which outlines the response required for a variety of incidents. Of most relevance to the current study is the Flood Response procedure which outlines the requirements for monitoring creek levels and road access, information dissemination and visitor management requirements, and interactions with the requirements of the Jabiru Counter Disaster Plan.

3.6.3.4 CURRENT ACTIVITIES FOR MANAGEMENT OF VALUES

A range of existing controls for management of the natural and cultural resources and tourist and visitor services of the SAR catchment are implemented by Park Management with many of the actions being undertaken through a district-based annual program of works. Table 3-8 outlines some of the current management measures taking place within Kakadu, including within the SAR catchment, under the relevant KRAs.

Table 3-8: Examples of current management measures to meet KRAs

KRA	CURRENT MANAGEMENT MEASURES
KRA 1 **Natural Resource Management**	• Monitoring of: – Weeds (e.g. salvinia) – Crocodile populations – Marine turtles (nesting flatback turtles at Field Island) – Impact of seasonal food source availability on magpie goose – Mangroves (long-term) • Tracking of large crocodiles into upstream habitats • Control programs – Control of weed species (e.g. salvinia) – Control of ferals (according to feral animal strategy) • Implementation of relevant Action Plans (e.g. Northern River Shark and Speartooth Shark)
KRA 2 **Cultural Heritage Management**	• Rock art protection work • Cataloguing and preserving cultural heritage materials • Collection of oral histories • Development of cultural heritage sites register • Implementation of outstations procedure • Study of traditional uses of the SAR floodplain
KRA 4 **Visitor Management and Reserve Use**	• Implementation of tourism masterplan • Continued effort to increase visitation patterns and experiences • Regular monitoring (inspections) and maintenance of visitor facilities • Improvement of tracking of visitor numbers • Promotion of cultural business and tourism • Monitoring for problem crocodiles in waterholes, and appropriate warning signs provided • Limits put in place for recreational fishers (location restrictions – Parks Australia, bag and size limits – NT Govt) • Permit system for back-country bushwalking and selected camping spots • Provision of visitor information

Other overarching measures for management of values are undertaken within the SAR catchment related to installation, maintenance and upgrades of infrastructure by Parks, the Northern Territory Government and private enterprise. For example:

- recreational fishing infrastructure maintenance (e.g. boat ramps) by Parks Australia;
- tourism infrastructure maintenance by private venture and Parks Australia; and
- road maintenance (annually) and upgrades by the Northern Territory Government and Parks Australia.

Further, the *Kakadu National Park Tourism Master Plan: 2009-2014 (Draft)* (Director of National Parks 2009) and *A Shared Vision for Tourism in Kakadu National Park* (Commonwealth of Australia 2005) guide the way tourism is managed in Kakadu (refer Section 3.5.2).

4 Impact Assessment

This section addresses the potential climate change impacts on the values of the SAR catchment. The assessment was undertaken using the results of the numerical models, and subsequent interpretation of the potential geomorphological change and ecological response. Key potential changes to the values outlined in Section 3 are described below.

For the purpose of outlining the impacts within different areas of the SAR catchment, the catchment was divided into catchment zones (refer Figure 4-1); coast, lower estuary, upper estuary, floodplain and freshwater. Due to the type of information available, the zonation was most appropriate for use in the assessment of changes to physical processes and ecosystem responses, where as a catchment-wide assessment was more suited for cultural and socio-economic assessments. Where possible, information on impacts within each zone was provided.

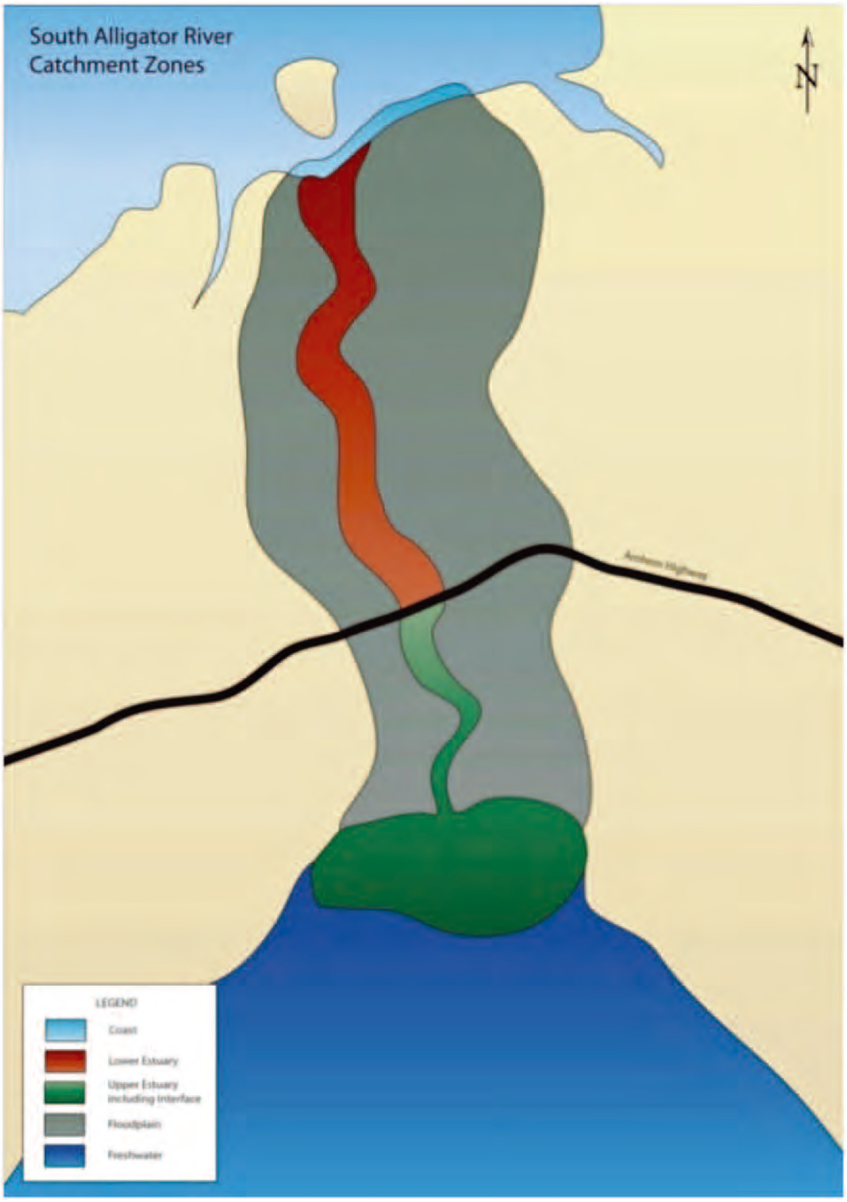

Figure 4-1: Schematic diagram of SAR catchment zones

4.1 CHANGES TO PHYSICAL PROCESSES

Changes to physical processes were assessed using numerical models as described in Section 2. These included catchment, tidal channel and floodplain, and cyclonic storm tide models. The developed models were calibrated to existing data sets where possible. They were then used to assess the impacts of climate change on the physical processes such as rainfall runoff, tidal flow and storm surge, and interpretation was made of potential geomorphologic impacts.

4.1.1 OVERVIEW OF MODELLING RESULTS

The climate change scenarios assessed through computer modelling were limited to the projected rise in sea level, increase in cyclone intensity and frequency, and change to rainfall. The assessment of the possible change due to the climate change scenarios was carried out by an extensive literature search and the development of numerical models. As outlined in Section 2, these models included:

- a catchment model which was used to route existing and projected future rainfall from the upper catchment to the tidal channel and floodplain areas;
- a cyclonic storm tide model which was used to assess the existing and projected changes in storm tide levels at the coast; and
- a tidal channel and adjacent floodplain model which was used for the existing and projected future scenarios to:
  - convey freshwater from the catchment model towards the coast;
  - convey tidal water and future SLR and storm surge inland; and
  - combine all sources of water (tide, SLR, storm surge and rainfall) in an integrated model.

The models used the following predictions for the 2030 and 2070 climate change scenarios:

- sea level rise:

  2030: IPCC emission scenario A1B, 95th percentile (143mm sea level rise); and

  2070: a high emissions scenario based on the latest science developed by DCCEE (700mm sea level rise).
- Rainfall scenarios based on the percentage change figures for Darwin as published by IPCC (2000; 2007b) and interpreted by CSIRO (2007).
- Changes in cyclone intensity and frequency with 2030 being represented by a 10% increase in intensity (only) and 2070 by a 20% increase in intensity and 10% increase in frequency (SEA 2009).[25]

4.1.1.1 CATCHMENT MODEL RESULTS

The freshwater flows and sediment loads from the 11,700 km^2 SAR catchment were modelled using the WaterCAST catchment modelling framework (refer Appendix I). The model was developed to assess potential climate change impacts on catchment flows, wet periods and dry periods, and to provide time series inputs to receiving water models. Limited data that was available was used to create and calibrate the model; therefore, the results of any one model scenario should not be viewed in isolation but in comparison with other scenarios.

The modelling indicated that changes to runoff volume as a result of climate change were approximately twice that of projected changes to rainfall on a percentage basis as shown in Figure 4-2. For the 2030 scenario, total catchment discharge was shown to increase (11%) or decrease (13%) depending on the climate scenario. For the 2070 scenario, runoff was shown to increase (38%) or decrease (37%) depending on the climate scenario.

25 As outlined in Section 2.1.2, the SEA (2009) report recommended use of a 10% increase in frequency by 2070. This was identified as a worst case scenario and was subsequently used as conditions for modelling.

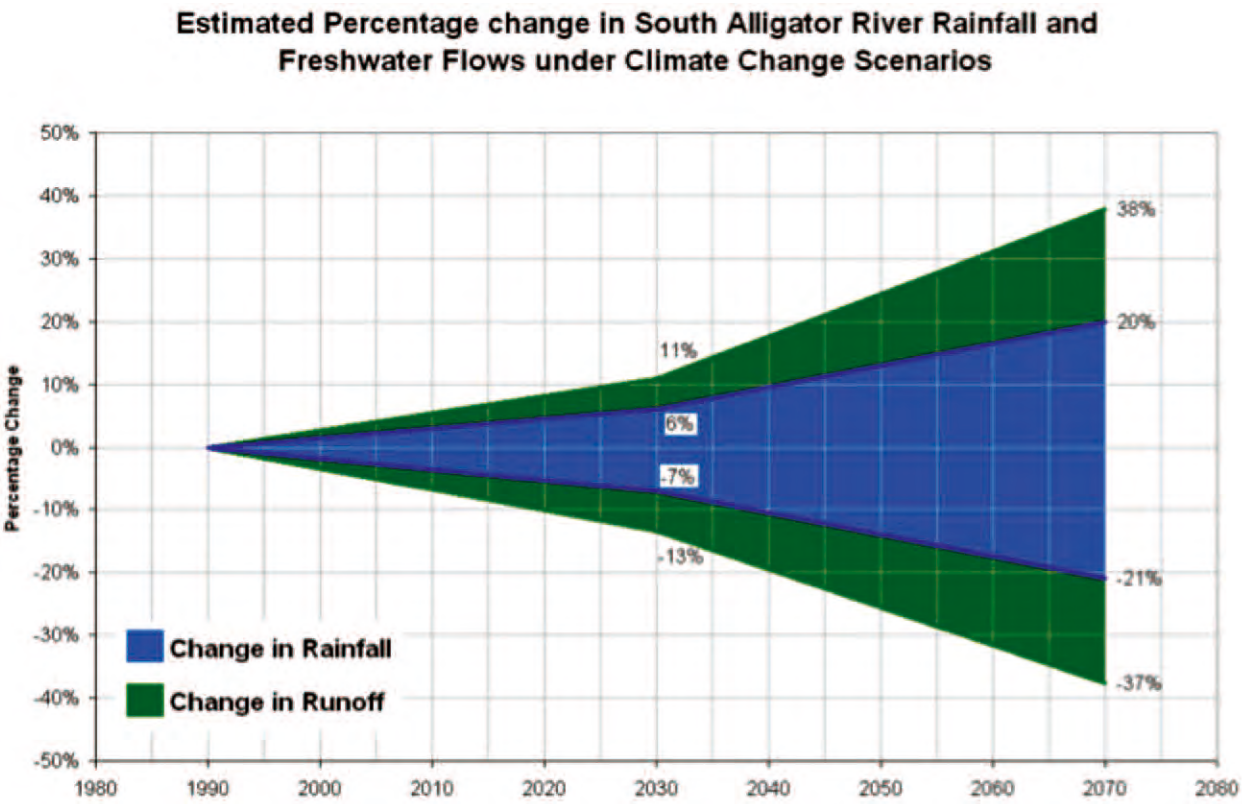

Figure 4-2: Estimated change in runoff with projected change in rainfall

Changes in runoff volume are associated with changes to water availability and duration of wet spells, dry spells and flood periods. The modelling results indicated that:

- The number of ‘dry’ days per year could increase by five days per year or decrease by up to five days per year for the 2030 scenario. For the 2070 scenario, the number of ‘dry’ days per year could increase by 18 or decrease by 13 days per year.
- The number of ‘wet’ days per year could increase by seven days per year or decrease by up to nine days per year for the 2030 scenario. For the 2070 scenario, the number of ‘wet’ days per year could increase by 18 or decrease by up to 34 days per year.
- Large flood events characterised by the top 1.5% of flows (currently 20 days average duration per year) could decrease by 12 days average duration per year or increase by 10 days average duration per year for the 2030 scenario. For the 2070 scenario large events could decrease to zero days average duration per year or increase by nine days average duration per year indicating the potential for climate change to significantly alter the large flood frequency, duration and flooding events.

4.1.1.2 CYCLONIC STORM TIDE MODEL RESULTS

Estimated existing and future statistical storm tide levels along the Kakadu National Park coastline were based on constructing a statistical model of the regional tropical cyclone climatology, combined with storm tide estimates from a parametric model and generating astronomical tides over a simulation period of 50,000 years. A full description of the model and results is given in Appendix J.

Figure 4-3 shows the components of storm tide for the existing condition. For future climate change scenarios the projected future storm tide will include the SLR plus extra surge due to more intense and frequent cyclones.

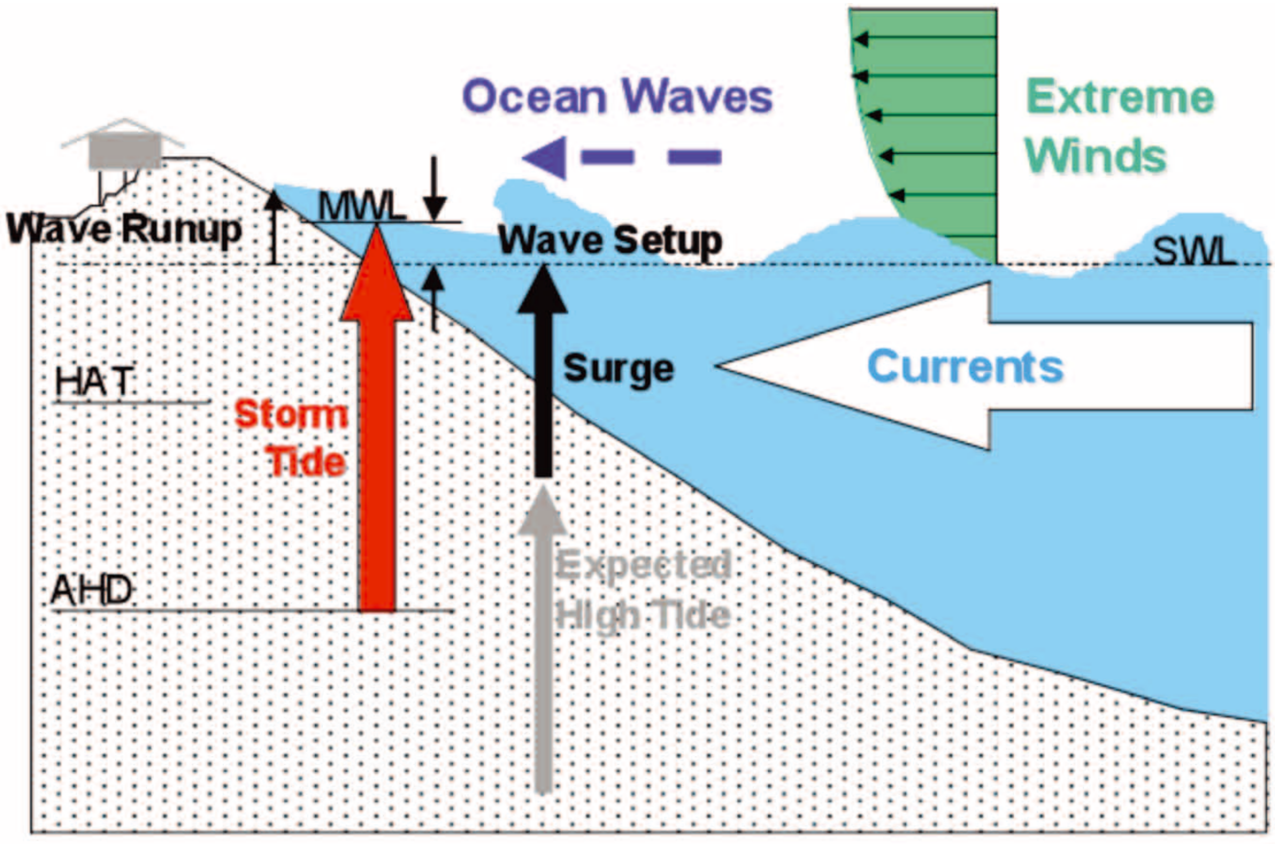

Figure 4-3: Water level components of an extreme storm tide (after Harper 2001 in SEA 2009)

The results of the cyclonic storm tide modelling showed only minor differences in the statistical storm tide levels with the projected climate change scenarios. In summary the results for the entrance of the SAR were:

- at 2030 with a SLR of 143 mm the projected increase in storm tide was an extra 150 mm; and
- at 2070 with a SLR of 700 mm the projected increase in storm tide was an extra 100 mm.

This includes consideration that increased sea level rise occurs with each tide and increased storm surge occurs in a cyclonic event. It should be noted that these increases in storm surge are the statistical averages over tens of thousands of possible cyclones and are not an indication of the possibility of a statistically rare event (say 1:1,000) with dramatic impacts occurring now or in the future. The smaller value for predicted increase in storm tide in 2070 from that projected for 2030 may be attributed to modelled variables such as increased water levels and the resultant decreased shoaling, and vegetation effects on waves, that can result in less surge.

4.1.1.3 TIDAL CHANNEL AND FLOODPLAIN MODEL RESULTS

The tidal channel and floodplain model was developed with a finite volume model that includes a flexible nodal network allowing efficient numerical schematisation of the tidal channel and floodplain downstream from Yellow Water. An example of part of this network is shown in Figure 4-4. A full description of the model and results is given in Appendix K.

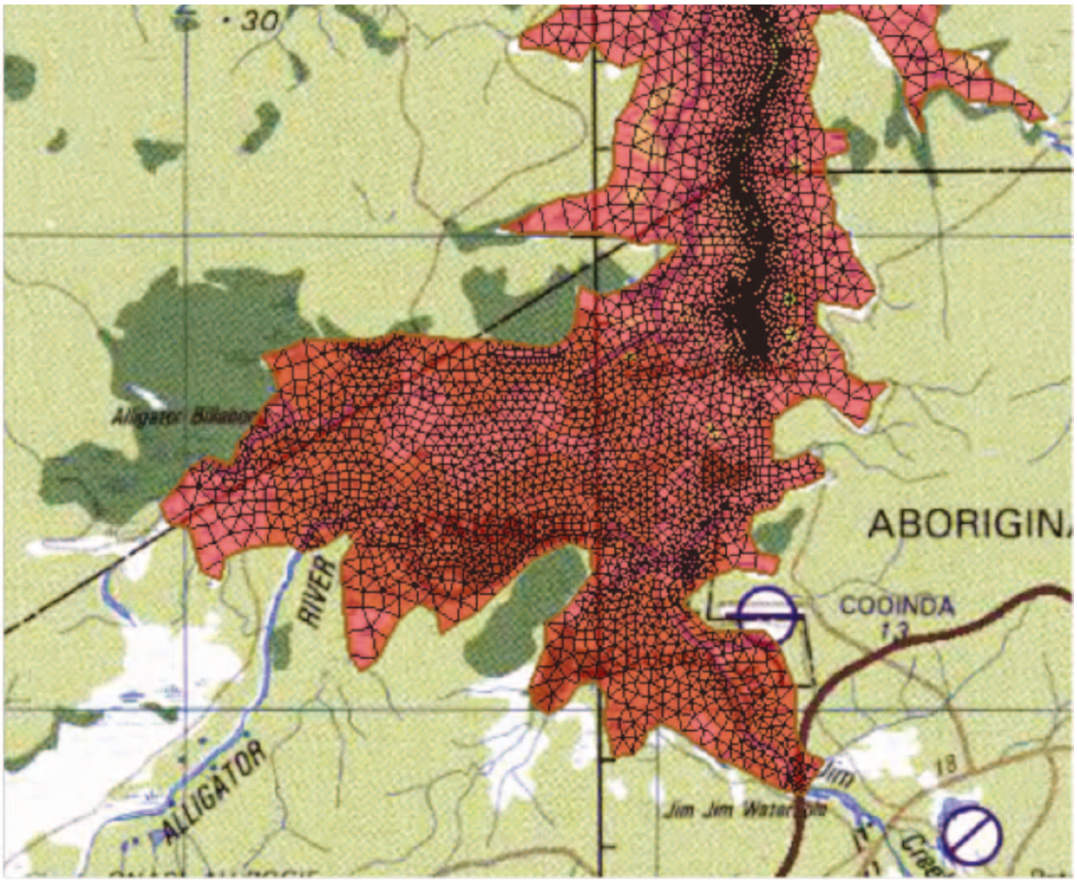

Figure 4-4: Part of tidal channel and floodplain nodal network

The tidal channel was developed from 25 cross sections surveyed in late 2008. At this time four tide gauges were also installed for about one month allowing calibration of the tidal model to the recorded data and high confidence in the results from this model.[26]

In particular the process of levee building was interpreted from previous publications (Vertessy 1990) as being related to sediment rich tidal water just overtopping the banks/levees in the tidal channel on spring tides. The elevation model was modified to include levees on the channel between Yellow Water and the bridge on the Arnhem Highway. These levees allowed limited overtopping to occur in the existing case and provided a gauge by which future climate change scenarios could be measured.

Initially, it was hoped to establish levels for the floodplain from a Shuttle Radar Topography Mission (SRTM) dataset (flown in 2000) which had been interpreted and improved by Geoscience Australia. However, the final Digital Elevation Model (DEM) still included vegetation and had a stated vertical accuracy of +/-3-5m with levels given in increments of 1 m. This was not suitable for the SAR floodplain which has levels which fall a metre or two in 100 kms. However, as the model has 10,000+ nodes it was decided to interpret a mean level from the SRTM DEM for the floodplain giving a level of about 5 m AHD. This level was used for the majority of the modelling, except for sensitivity testing in which lower levels were used. These lower levels were based on information from literature searches and local input to give a level of about 2-4 m AHD[27]. Note that the impact assessment in this Section is based on use of 5 m AHD and the use of levees constraining the majority of tidal flow to the main channel.

26 Surveys and installation of tide gauges were undertaken by Dave Williams (previously of NRETAS, now of the Australian Institute for Marine Science (AIMS)).

27 Future modelling would be much improved by having accurate definitions of the levees and the floodplain.

Due to the lack of definitive levels, the flat nature of the floodplain and the subtlety of features such as the levees and paleochannels the floodplain model was only able to give indicative results. However, its accuracy was sufficient to give a reliable indication of changes to hydraulics due to the climate change inputs.

The downstream boundary of the combined tidal/floodplain model was driven by the tidal levels recorded in 2008 and extended with reference to the Darwin gauge. Impact scenarios had SLR and storm surge changes added to this boundary. The upstream boundary conditions were flows and sediment inputs related to rainfall changes (refer to Appendix I).

The tidal/floodplain model indicated that the SLR plus storm surge predictions provided the most definite response as these increased water levels were efficiently propagated to the tidal head and caused the levees in this region to be overtopped more frequently. This definitive response was easily observed in the model because the flows in the tidal channel dominated during the dry season and changes to the downstream water levels were therefore easily noticeable. In contrast, during the wet season the flows were dominated from freshwater flowing off the catchment and across the floodplain and therefore changes in downstream water levels were somewhat overwhelmed.

In summary, the model demonstrated the following impacts:

- Tide heights increased by the SLR component for much of the tidal channel.
- Both the existing tide and "tide + SLR + surge" propagated efficiently to the upper estuary.
- Increased overtopping of bank/levee with predictions of about a 60% increase in 2030 and 500% increase in 2070 (refer Figure 4-5 which shows a typical spring tide period). Note that the lack of a detailed DEM of the floodplain prevents estimation of the volume and extent of this overtopping.
- Sea level rise demonstrated very efficient tidal propagation into the estuary resulting in greater pressure on the tidal head and the extension of this area towards Yellow Water.

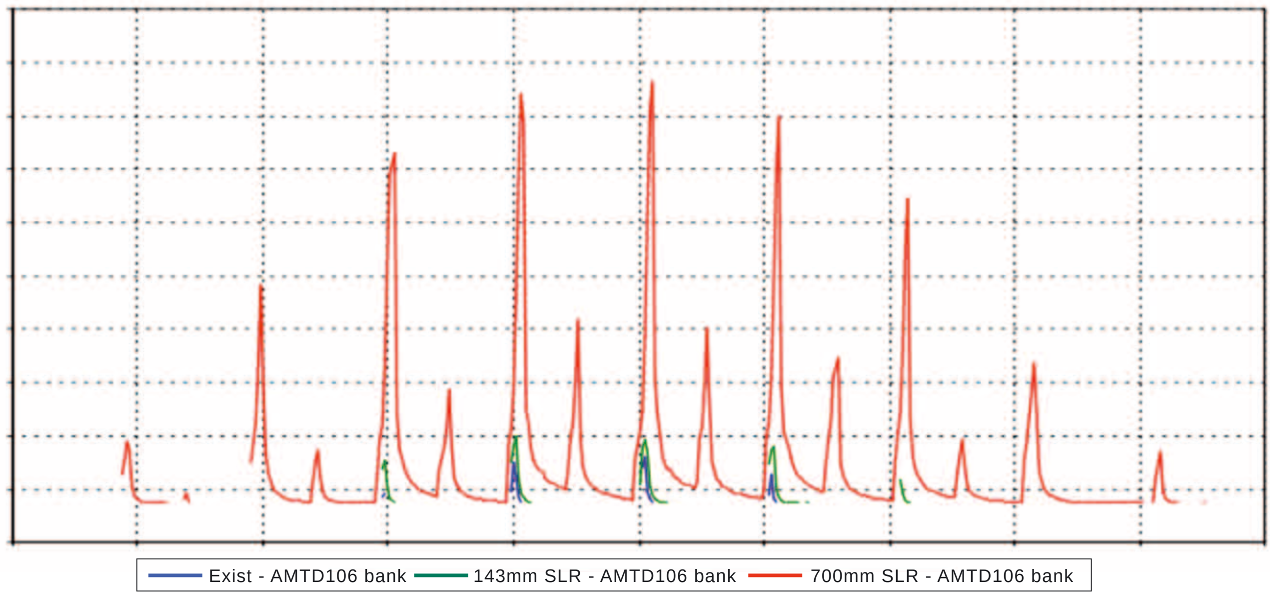

Figure 4-5: Increased overtopping of levees in the upper estuary

Interpretation of these results with respect to the tidal component suggests there will be increased tidal pressure on dendritic channels which may tend to keep them open longer or force them to extend further onto the floodplain and deliver saltwater to these areas. Also, increased tidal flows and velocities in the main channel will be experienced due to increased tidal prism and this may result in increased scouring. This impact may be dramatic if tide levels overtop the river banks and/or levees more often and will also cause significant changes if a greater volume of tidal water flows onto the floodplain through overtopping of the levees.

The combined affect of the expanding system of dendritic channels and increased levee overtopping is likely to result in increased saltwater intrusion during the dry season. There is a subsequent increased likelihood of billabongs being infiltrated by saltwater due to the above, and this is considered more likely for those already threatened and those adjacent to tidal/dendritic channels. It is not expected that sea level rise will impact on salinity within the tidal channel.

These interpreted results are based on the efficiency of future sea level rise propagation up the estuary as demonstrated by the model and therefore increased potential for overtopping of the natural levees. While morphological change is likely to be experienced due to increased capacity to mobilise and transport sediments, a conservative approach has been adopted in interpreting the above changes and it has been assumed that the natural levee building process is not able to respond quickly enough to SLR and the levee growth will lag behind SLR.

Note that there is a possibility that the levee system as well as the banks along the entire estuary channel could be overwhelmed by the projected sea level rise. This would have dramatic impacts on salinity of the floodplain. Anecdotally, it has been reported that 'surges' in the SAR cause bank/levee overtopping and massive salinity damage that lasts for many years. The lack of definitive elevation data has not allowed an accurate assessment of this possibility.

With respect to salinity levels within the river itself, the modelling has indicated that the flows experienced during the wet will still be sufficient to overwhelm the salinity of the tidal channel over almost the full length of the estuary.

4.1.2 SUMMARY OF THE PHYSICAL PROCESS IMPACTS WITHIN SAR CATCHMENT ZONES

The processes discussed in Section 3.2 and the predicted changes outlined above act both in isolation and interact with other physical processes. Interpretation of the key results and interactions between these processes is outlined below for each of the catchment zones of the SAR.

4.1.2.1 COASTAL ZONE

In the coastal zone, the predominant physical process impacts will be related to sea level rise (143 mm at 2030, and 700 mm at 2070) and storm surge (150 mm at 2030, and 100 mm at 2070), with increased sea level rise occurring each tide and increased storm surge occurring in a cyclonic event. No attenuation of these impacts will be discernable in the coastal zone. Further, rainfall changes and impacts to salinity levels in this zone will be negligible.

4.1.2.2 UPPER AND LOWER ESTUARY

The results of climate change impacts from each of the models will affect the upper and lower estuary zones. These are summarised below:

- Tide heights increased by the SLR component for much of the tidal channel.
- Climate change impacts demonstrated a strong tidal push into the estuary with tidal saltwater propagating efficiently to the upper estuary.
- Under the 2030 scenario, saltwater was present at times at the tidal head but drained away after most events. Under the 2070 scenario, the saltwater was present at the tidal head more often and to a greater depth and subsequently took longer to drain away.
- Wet season flows will still revert most of the estuary to freshwater.
- Increased flows and velocities will be experienced due to an increased tidal prism. This may be dramatic if tide levels overtop the river's bank and levee system.
- The increases in flows and velocities are likely to increase the capacity for mobilisation and transport of sediments.

4.1.2.3 FLOODPLAIN ZONE

Similar to the upper and lower estuary zones, the results of each of the models provided combined impacts in the floodplain zone. These are:

- The increased overtopping of the levees due to sea level rise and storm surge demonstrated that saltwater inundated the floodplain more frequently (by 60% in 2030 and 500% in 2070). [28] Note that the lack of a detailed DEM of the floodplain prevented estimation of the volume and extent of this overtopping.
- Expansion of the dendritic channels may cause saltwater intrusion impacts to extend further into the floodplain, however during the wet season, flows will still revert most of the floodplain to a freshwater system.
- Those billabongs already threatened or those adjacent to tidal/dendritic channels will have an increased likelihood of being impacted by saltwater intrusion.

It has not been possible to assess the potential for the natural levee system and banks along the entire estuary channel to be overwhelmed by the projected sea level rise. If this were to happen there would be dramatic impacts on salinity of the floodplain.

4.1.2.4 CATCHMENT ZONE

At the downstream extremities of the existing catchment zone, there is potential for impacts from sea level rise and storm surge in extreme events, but these are considered to be negligible. The dominant changes demonstrated by the model within the catchment zone will be due to changes in rainfall and runoff, as outlined in Section 4.1.1.1.

4.2 CHANGES TO ECOSYSTEMS

Interactions between climate and key physical (refer Section 4.1.1 and 4.1.2), biogeochemical and biological processes together control wetland ecosystems. Consequently, climate change has the potential to fundamentally affect a range of wetland ecosystem functions, features and processes across a number of levels (refer Table 4-1).

The following sections examine the potential impacts of sea level rise and altered rainfall patterns on ecosystem values and processes. These impacts were primarily determined through an assessment of the potential sensitivity of the key habitats and EVs to predicted changes in tidal and fluvial processes, thereby enabling ecological responses to be predicted. Details of these potential responses of key habitats and EVs are presented in Appendix G.

It is important to note that SLR represents only one component of climate change, and is linked to numerous other interacting climate change processes. Furthermore, various secondary impacts may arise including, for example, increased physical disturbance to habitats and species resulting from increased frequency of cyclones, changes in ecosystem processes resulting from altered fluvial flow regimes, and loss of habitat connectivity. While it is beyond the scope of the present study to examine other processes in detail, we have noted where such interactions exist in the context of the present study.

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28 Note that this is based on the assumption that the natural levee system is not able to respond to the SLR increases.

Table 4-1: Summary of ecosystem features and processes likely to be influenced by climate change (modified after Sheaves *et al.* 2007)

FEATURE OR PROCESS	CLIMATE CHANGE PROCESS WITH GREATEST POTENTIAL IMPACT	ASPECTS LIKELY TO CHANGE
Physical processes relevant to ecosystems	**sea level change** rainfall patterns **severe weather events** acidification temperature	coastal/estuarine geomorphology estuarine flushing sediment loads nutrient transport salinity profiles ecosystem-specific chemistry fire regimes
Habitats and ecosystems	**sea level change** rainfall patterns **severe weather events** temperature	extent of particular habitats/ ecosystem components relative proportions of habitats habitat interspersion, patch size, pattern & connectivity habitat boundaries habitat availability fire regimes
Species & species-level ecological functions	**sea level change** rainfall patterns **severe weather events** acidification secondary outcomes from effects on habitats and species temperature	abundance distribution spawning supply of recruits or propagules temporal & spatial matching with prey/nutrients
Trophic function	secondary outcomes from effects on habitats, species and diversity	food web structure and integrity physically mediate nutrient flows biologically mediated nutrient flows balance of export/import dominant trophic processes
Connectivity	**sea level change** rainfall patterns **severe weather events** secondary outcomes from effects on habitats and species	physical connectivity biological connectivity overall ecosystem linkages
Higher level ecological functions	temperature **sea level change** rainfall patterns **severe weather events** acidification secondary outcomes from effects on habitats, species and diversity	nursery ground function ecosystem/habitat dependence regularity/periodicity of ecosystem structuring events (e.g. cyclones, fires) changes in complex ecosystem interactions changes in structure of production models impacts on key ecosystem components fisheries production

FEATURE OR PROCESS	CLIMATE CHANGE PROCESS WITH GREATEST POTENTIAL IMPACT	ASPECTS LIKELY TO CHANGE
Diversity	temperature **sea level change** rainfall patterns **severe weather events** acidification	taxonomic diversity functional diversity
Interactions with anthropogenic factors	**sea level change** rainfall patterns **severe weather events** acidification secondary outcomes from effects on habitats, species and diversity	interactions with anthropogenic stressors interactions with human response to climate change

KEY:
Bold – refers to processes specifically considered in this report

4.2.1 GENERAL ECOSYSTEM RESPONSES

Sea level rise, combined with associated shoreline erosion and saltwater intrusion, will result in the losses and gains of coastal, estuarine and freshwater wetland resources (Eliot *et al.* 1999). The biodiversity consequences due to SLR can be grouped into four key 'currencies' based on the *Garnaut Climate Change Review – Biodiversity and Climate Change* (MacNally *et al.* 2008).

- **Species abundances.** Climate change will provide favourable conditions and therefore potential increases in the relative abundance of some species (such as mangroves and other estuarine flora and fauna), and declines in the abundance of others that are intolerant of the new environmental conditions and are unable to move to a suitable habitat.
- **Invasive species.** As changes in environmental conditions trigger the movement of species, niches become available for colonisation. Should exotic species be more suited to the new environmental conditions, these exotic species may proliferate while native species may suffer reductions in available habitat and/or suitable resources. On the other hand, should new environmental conditions not be favourable for existing invasive species, these species may experience reductions in extent.
- **Ecosystem processes and services.** Trophic function and ecosystem integrity is likely to be affected both directly, and as a secondary flow-on through changes to habitats, species distribution and abundance, connectivity and biogeochemical processes.
- **Unanticipated changes.** There is a clear need for better information on the physical characteristics of the landscape, the functioning of wetland ecosystems and the resilience of individual species to climate change in order to make more accurate predictions. However, even with further information, there will undoubtedly be a range of unanticipated changes that cannot be predicted given the complexity and stochastic nature of wetland ecosystems.

From an ecosystem perspective, the following broad impacts would be expected within the SAR from the climate change scenarios provided:

- changes to fringing coastal wetlands, including the coastal mangrove fringe and adjacent saltmarsh and freshwater wetland communities;
- in-channel changes consisting of:
  - colonisation of mangrove species along creek lines due to a shift in the tidal head;
  - inundation and loss of Melaleuca wetland vegetation on the margins of some wetlands.

- changes to floodplain and freshwater habitats, most notably the replacement of freshwater wetlands (floodplains and billabongs) with saline mudflats (and possibly saltmarsh and mangroves in low-lying areas).

It is noteworthy that migration to suitable habitat in adjacent areas may offer some species a means to circumvent climate change impacts. However, the potential for migration is uncertain as nearby systems that support similar habitats are likely to be similarly impacted by climate change. Furthermore, not all species have the ability to display migratory adaptive behaviour, and the benefits of inhabiting a protected area may be lost to populations that migrate to outside of Kakadu National Park.

Ecosystem responses and their implications are described below for each of the zones, with a summary of potential impacts to EVs presented in Table 4-2 (note that the likelihoods of these potential impacts are considered in the following chapter).

Table 4-2: Assessment of potential impacts to key EV species and habitats

KEY ENVIRONMENTAL VALUES		POTENTIAL IMPACTS
Freshwater		
Freshwater macrophytes		Decrease in freshwater flora extent • Habitat loss due to SLR • Mortality within some species (saltwater intrusion) • Measurable changes to ecosystem components but no loss of functions
Monsoon rainforest		Decrease in monsoon rainforest extent • Habitat loss due to SLR • Mortality within some species (saltwater intrusion) • Measurable changes to ecosystem components but no loss of functions
Woodlands		Decrease in woodlands extent • Habitat loss due to SLR • Mortality within some species (saltwater intrusion) • Measurable changes to ecosystem components but no loss of functions
Pig-nosed turtle		Decrease in pig-nosed turtle abundance • Habitat loss due to SLR • Reduced reproductive success
Potodramous fish		Decrease in potodramous fish abundance • Habitat loss due to SLR • Mortality within some species due to saltwater intrusion • Loss of habitat connectivity due to reduced rainfall
Freshwater crocodile		Decrease in freshwater crocodile abundance • Habitat loss due to SLR • Reduced reproductive success
Magpie goose		Decrease in magpie goose abundance • Habitat loss due to SLR
Brolga		Decrease in brolga abundance • Habitat loss due to SLR

KEY ENVIRONMENTAL VALUES		POTENTIAL IMPACTS
Estuarine/Freshwater Transitional		
Barramundi		Change in barramundi abundance • Nursery habitat loss due to SLR but possible increase in adult habitat • Uncertain population response. Reduced rainfall and loss of freshwater habitat likely to be key impacting processes (reduced floodplain connectivity etc.) which could offset beneficial impacts
Saltwater crocodile		Reduced saltwater crocodile reproductive success • Nesting habitat loss due to SLR but possible increase in adult habitat • Reduced nesting success due to high rainfall • Highly uncertain population response. Other climate change factors (e.g. temperature effects on sex ratios) likely to be key control on populations
Yellow chat		Decrease in yellow chat abundance • Loss of freshwater wetland habitat due to SLR • Retraction in coastal saltmarsh habitats (but possible expansion into other areas)
Estuarine/Marine		
Mangroves and saltmarsh		Decrease in mangrove and saltmarsh extent • Retraction in coastal mangrove fringe but possible expansion into other areas • Measurable changes to ecosystem components but no loss of functions
Mud crab		Decrease in mud crab abundance • Loss of habitat due to retraction of coastal mangrove fringe (but possible expansion into other areas)
Threadfin salmon		Decrease in threadfin salmon abundance • Loss of habitat due to retraction of coastal mangrove fringe (but increase in estuarine habitat, including recruitment and feeding areas)

Ecosystem responses within each of the SAR catchment zones (refer Figure 41) are discussed below.

4.2.2 COASTAL ZONE ECOSYSTEM RESPONSES

The distribution, extent and community structure of coastal ecosystems is regulated by the interplay between oceanographic (sea levels, tidal) and hydrological (surface water and groundwater) processes, as well as local soil, morphological and vegetation patterns. A change in one or more of these fundamental drivers will affect patterns in space and time of these coastal communities, with the following ecosystem responses expected.

Landward Retreat of Mangroves

Mangroves generally occur between mean sea level and the highest astronomical tide, inhabiting the seaward fringe and dendritic drainage channels. As mangroves are sensitive to small changes in tidal levels and occur in areas with limited topographic variation, SLR of only a few centimetres is expected to impact mangrove communities. Assuming that the tidal profile has a relatively flat and steady gradient, some loss of existing mangrove communities would be expected for both the 2030 and 2070 scenarios (143 mm and 700 mm SLR respectively). This mortality would be particularly notable along the seaward fringe. However, as mangroves are capable of rapid colonisation, should suitable environmental conditions exist (i.e. regular tidal inundation, suitable soil conditions), as sea level rise occurs, a landward retreat of mangrove extent may be observed due to upland conversion to tidal wetlands. Direct losses of coastal wetlands due to SLR could therefore be offset, at least in part, by inland wetland migration.

It is not possible at this stage to determine whether there will be a net change in extent of mangroves due to (i) absence of suitable topographical data to model the distribution of the newly created intertidal zone; and

(ii) uncertainties regarding the rate of change in sedimentation processes and its effect on habitat availability. However, increased tidal forcing would be expected to result in the creation of additional dendritic channels (and associated mangrove habitat) across the saltpan, and in the longer term, could completely inundate the saltpan areas. Provided that these areas are adequately flushed and salinity levels are maintained at or near seawater, it is likely that SLR will result in a net increase in mangroves compared with existing conditions.

Assuming an increase in mangrove extent, an increase in habitat and food resources would be expected for mangrove associated fauna species. As such, it is expected that there would be positive impacts on fish and shellfish EV species, including:

- an increase in spawning habitat and recruitment areas for barramundi (i.e. quiescent areas near mud flats and creek mouths);
- an increase in nursery habitat for mud crabs and threadfin salmon (and other economically significant shellfish and fish species, such as banana prawns and most coastal finfish species);
- a possible increase in prey resources in the form of juvenile finfish and shellfish, and possibly mangrove-associated macroinvertebrates (i.e. crabs, worms, molluscs etc).

There is however insufficient information to determine under what conditions habitat availability limits populations of these species, and therefore the response of fish and shellfish stocks to an increase in habitat availability. It is also important to note that many species that occur in mangroves (and saltmarsh) also occupy freshwater wetlands during part of their life cycle (e.g. barramundi). Hence, a loss of freshwater wetlands could lead to detrimental impacts to some species despite positive impacts during their marine life-stages. This issue is considered further below.

Changes in Saltmarsh Extent

The landward advancement of mangroves will replace adjacent community types, predominantly adjacent low-lying saltmarsh and saltpan communities. In turn, the possible loss of saltmarsh habitat due to mangrove encroachment may be offset by expansion of saltmarsh/saltpan into other less salt tolerant habitats, again depending on local topography and soil conditions. The limited available topographical data suggests that adjacent areas are low lying and have a low gradient, enhancing opportunities for this serial colonisation. Based on broad scale vegetation mapping, it would appear that palustrine wetlands (possibly freshwater) occur landward of the saltpan/saltmarsh area. In the absence of detailed modelling results, it is not possible to determine whether catchment runoff will in the future be sufficient to significantly restrict the extent of saltwater intrusion into these wetland habitats, nor how often these wetlands are inundated by saltwater at present. It is reasonable to assume that there will be a higher likelihood of saltwater inundation and saltmarsh encroachment assuming lower rainfall (i.e. increased length of dry spells, lower total runoff etc).

Changes in saltmarsh extent would be expected to result in changes in habitat availability for saltmarsh associated fauna species. These include the EV species brolga and yellow chat that use saltmarsh for feeding (and nesting). However, if there is a net saltmarsh loss, major changes in the population statuses of these species are not anticipated as both of these birds preferentially utilise floodplain habitats. Furthermore, if saltmarsh advances landward, negative consequences to saltmarsh fauna may be (partially) mitigated.

Note that the impacts of the loss of freshwater communities are considered in the following sections.

Invasive Species

As weeds and feral animals are uncommon in the coastal habitats, predicted changes in environmental conditions are unlikely to result in major changes in the distribution and abundance of pest species.

4.2.3 IN-CHANNEL (UPPER AND LOWER ESTUARY ZONES) ECOSYSTEM RESPONSES

The distribution and community structure of vegetation and fauna communities within the river and creek channels are controlled by a range of physical (inundation patterns, current velocities), physio-chemical (porewater salinity), and biological (competition) processes. These processes are to a large extent controlled by the interplay between tidal and fluvial processes, such that the responses detailed below are expected for in-channel ecosystems.

Increase in Upstream Extent of Mangroves

Due to the progression of the tidal head upstream, it is expected that there will be an upstream shift in the distribution of mangroves for both the 2030 and 2070 scenarios. Based on the decreased rainfall scenario, it is expected that there will be an increase in the length of the dry season and a reduction in annual flows. Under this scenario, oceanographic processes will tend to dominate and the changes in mangrove extent could be accelerated relative to the increased rainfall scenario.

The increase in total length of mangroves along the channel will increase habitat availability for commercially significant fish, crab and prawn species, including EVs such as barramundi, mud crabs and threadfin salmon (although as discussed previously, it is uncertain whether there will be a proportional increase in abundance of these species). Similarly, available habitat for adult saltwater crocodile feeding, basking and refugia will be increased.

Loss of Freshwater Habitats and Species

Due to the predicted increase in length of estuarine and brackish waters, estuarine communities are expected to increase in extent. These estuarine communities will have different ecological functions and values to the freshwater habitats that they replace, including:

- loss of freshwater macrophytes and salt sensitive littoral vegetation;
- loss of freshwater reptiles, fish and aquatic macroinvertebrates (including EV species such as freshwater crocodile and potadromous fish); and
- loss or change in food resource availability for species that feed on freshwater macrophytes, freshwater macroinvertebrates and/or freshwater fish (i.e. all species that feed in freshwater channel environments). While some species have a relatively flexible diet (e.g. barramundi, saltwater crocodile) and could feed on the more salt tolerant species that replace the freshwater assemblages, other species with a more specialist diet (e.g. magpie goose) will suffer a reduction in food resource availability.

These changes to particular sections of the channel are likely to become less pronounced as the distance from the coast increases. It is likely that SLR modelled in this study will cause saline intrusion into the Yellow Water complex, but upstream of this the extent may be restricted by the natural geographical rise in surface elevation.

It is uncertain as to how increases in current velocity are likely to impact ecosystem components. It is possible that disturbance to habitats due to increased flow may have negative impacts on species that favour more tranquil habitats, such as some submerged and emergent macrophytes. Furthermore, increased flows may have unfavourable impacts on some aquatic fauna species, especially during breeding seasons.

Reductions in Weeds

Several weed species occur in the freshwater reaches of creek environments, although most of the significant weed problems within the SAR catchment occur in floodplain areas. Higher salinities will provide sub-optimal conditions for weeds, possibly leading to localised reductions in weed cover in some areas. Feral animals are not known to particularly favour upper or lower estuary habitats. Therefore, no or slight, highly localised negative impacts to feral animal populations are expected.

4.2.4 FLOODPLAIN ZONE ECOSYSTEM RESPONSES

Patterns in vegetation community structure in floodplain habitats are a function of many interacting factors, including (but not limited to) frequency, depth and duration of inundation; salinity of surface and pore waters; soil type; and fire regimes. Of importance in the context of the present study is the effect of increased inundation (due to tidal and fluvial processes) and increased salinity.

Sea level rise will potentially result in an increased incidence in levee overtopping by high tides, leading to an increased incidence (frequency and possibly duration) of floodplain and billabong inundation by saline marine waters. The likelihood of levee overtopping will depend on the rate of levee bank sedimentation relative to the rate of SLR, which are both unknown at present. Assuming that the increase in levee overtopping did translate to an increase floodplain inundation, the following vegetation community structure and habitat changes would be expected.

Melaleuca Mortality on Wetland Margins

Due to the sensitivity of Melaleuca to salinity, an increased incidence of Melaleuca mortality is expected on the margins of some wetlands. Melaleuca swamp forests represent the key vegetation community for provision of roosting habitat for waterbirds, including EV species (e.g. magpie geese). Consequently, mortality of Melaleuca swamp forest is likely to have negative impacts in terms of a decrease in availability of roosting sites. As no other structurally similar vegetation communities are present within the freshwater floodplain, it is unlikely that a shift in habitat preferences will provide a means to alleviate this impact.

Melaleuca swamp forest mortality is also likely to impact aquatic fauna that utilise these habitats for spawning, refugia and feeding, including EV species such as barramundi.

Loss of Freshwater Wetland Vegetation

Hydrological changes, including the frequency and duration of inundation as well as the salinity, are expected to have major impacts on freshwater wetland vegetation. Should an increase in frequency of levee overtopping occur, some loss of freshwater wetland vegetation is expected. Vegetation communities may display a shift to more salt-tolerant communities such as mangroves and saltmarsh or saline mudflats. Note that the impacts of increased mangrove habitats have been discussed above.

Loss of freshwater wetlands will lead to a reduction in habitat and food resources for a vast number of freshwater wetland fauna species. Particularly notable, changes in vegetation that result from increased inundation will translate to the loss or degradation of nest sites for species that require herbaceous ground cover. These include EV species such as saltwater crocodiles, freshwater turtles and magpie geese, as well as a range of other water bird species. Furthermore, increased water levels may have detrimental impacts on the nesting success of significant fauna species. Saltwater and freshwater crocodile eggs are particularly sensitive to flooding, especially by saltwater. Inundation influences the length of pig-nosed turtle egg incubation, with eggs of this species also known to be susceptible to saltwater.

Loss of Billabongs

Loss of billabongs may occur as a result of saline inundation rendering billabongs as unsuitable habitat for freshwater flora and fauna, or alternatively may occur as a result of increased drying. Loss of billabongs freshwater flora may include species that are of bush tucker significance and/or valuable food resources for native fauna. Additionally, loss of billabongs will lead to a reduction in available habitat for a diversity of freshwater aquatic reptiles, fish and invertebrates, including EV species such as freshwater crocodiles, pig-nosed turtles and potadromous fish.

Decrease in Weed and Feral Abundance

The most notable weed species of Kakadu are associated with freshwater floodplain and wetland habitats. Species such as *Mimosa* and *Salvinia* are likely to decrease in abundance following saline inundation due to the sensitivity of these species to salinity, while other species such as Olive Hymenachne and Para Grass are more tolerant of salinity and may therefore persist. Should extensive floodplain drying occur, it is possible that terrestrial weed species such as Gamba Grass may become problematic in these areas. Replacement of freshwater wetlands with saline mudflats will lead to a loss of grazing lands for feral animals including pigs, horses and buffalo, and consequently climate change may potentially have beneficial impacts for the control of feral animals.

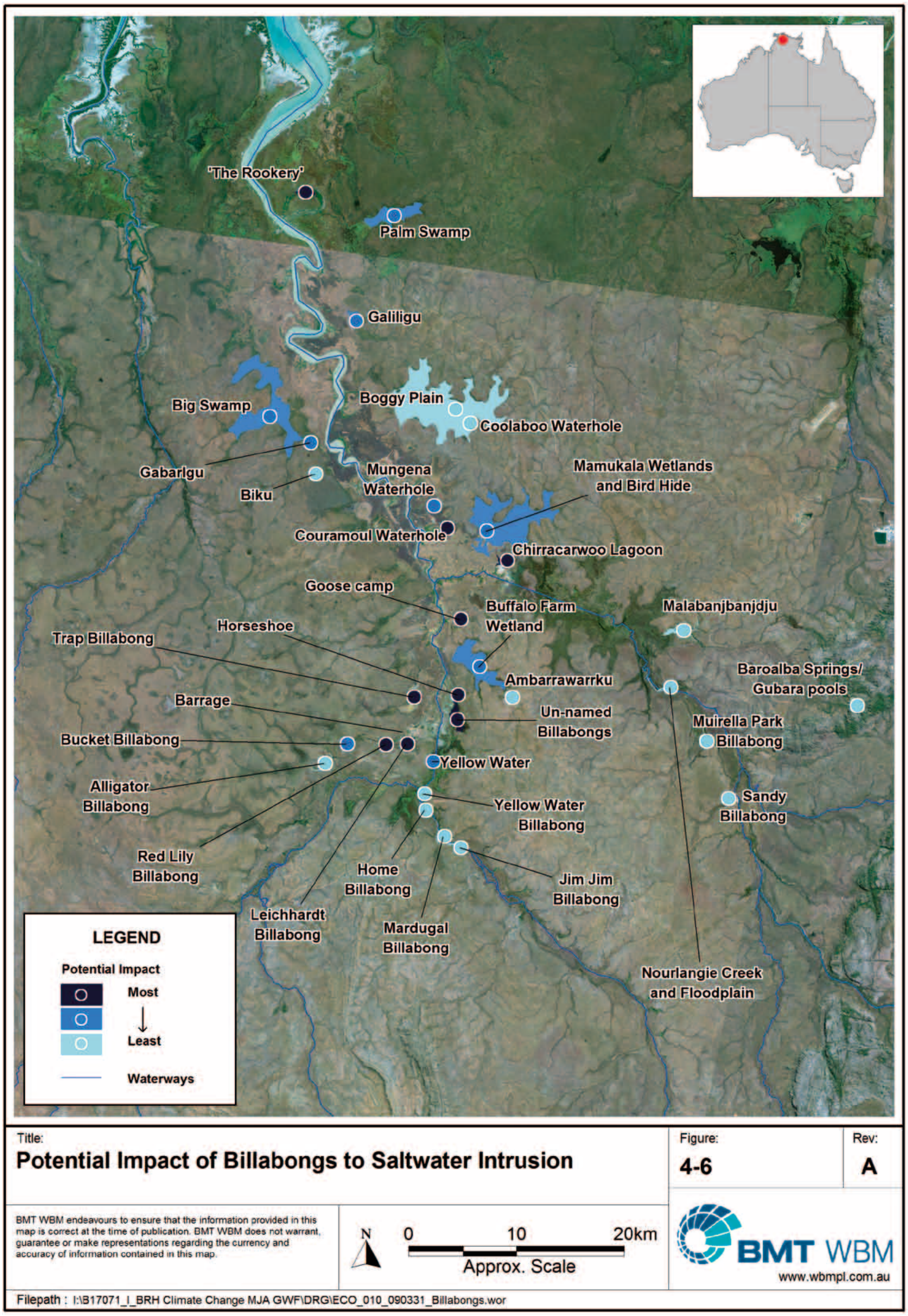

Figure 4-6: Relative risk of billabongs to saltwater intrusion

Relative Vulnerability of Billabongs and Freshwater Wetlands

In the absence of numerical modelling it is not possible to make quantitative estimates of changes to floodplain inundation. However, a high level qualitative assessment was undertaken of the relative potential impact of various billabongs to saltwater intrusion, which is based on: (i) their proximity to the tidal channel (based on the assumption that billabongs in close proximity to tidal channel are more sensitive than distant billabongs) and (ii) anecdotal records of tidal inundation of various billabong habitats (based on stakeholder consultation). The results of this assessment (refer Figure 4-6) indicated that:

- With the exception of Horseshoe Billabong and the unnamed billabong, areas of mapped Melaleuca communities do not have a high potential impact rating. Rather, Melaleuca communities mostly either have a medium potential impact rating (Palm Billabong, Galiligu Billabong, Big Swamp, Bucket Billabong) or low potential impact rating (Boggy Plain, Alligator Billabong, Home Billabong, Nourlangie Creek);
- Several areas of monsoon rainforests lie in close proximity to billabongs that have a high potential impact rating, including Leichhardt Billabong, Horseshoe Billabong, the unnamed billabong and Couramoul Waterhole, while few areas of monsoon rainforests lie in close proximity to billabongs that have a medium potential impact rating (Bucket Billabong) or low potential impact rating (Alligator Billabong);
- Areas identified as particularly important for magpie geese either have a medium potential impact rating (Big Swamp, Mamukala Wetlands) or low potential impact rating Boggy Plain.

4.2.5 FRESHWATER ZONE ECOSYSTEM RESPONSES

Patterns in vegetation community structure in the freshwater zone are primarily determined by the same factors as described for the floodplain zone, including frequency, depth and duration of inundation; salinity of surface and pore waters; soil type; and fire regimes. As such, expected climate change impacts in the freshwater zone are similar to those predicted for the floodplain zone, largely focussed on increased incidence (frequency and possibly duration) of inundation by saline waters into freshwater habitats (refer Section 4.2.4). Specifically, these impacts may include the following (as described in further detail in Section 4.2.4):

- dieback of Melaleuca stands in areas impacted by saline water intrusion;
- freshwater vegetation mortality (or decrease in cover) in areas impacted by saline water intrusion;
- reduction in food and nesting resources for freshwater wetland fauna species that inhabit vegetation communities in areas impacted by saline water intrusion; and
- uninhabitable waterbodies for freshwater fish and reptiles areas impacted by saline water intrusion.

However, the extent and magnitude of impacts in the freshwater zone is predicted to be lower than the magnitude as predicted for the floodplain zone. This is principally due to the position of this zone in the upper catchment resulting in lower likelihoods for levee overtopping and channel expansion than for areas that are closer to the river mouth (i.e. the expected extent/magnitude of impact decreases with increasing distance from the coastline).

On the other hand, it is possible that climate change may favourably impact the freshwater zone under the scenarios that predict increased rainfall. This is due to the potential for an expansion and/or increase in permanency of freshwater habitats and vegetation communities as a result of increased freshwater input into ecosystems (i.e. via rainfall). In turn, wetland fauna would be expected to benefit from the increased availability of food and habitat resources under these scenarios.

4.3 CULTURAL CHANGES

> *'We are all learning and we are all getting ready for climate change' - Jacob Nayinggul, Manilagarr clan, Chair Kakadu Board of Management*

Past climatic change is evident in the rock art and dreamtime stories of Kakadu. Bininj cite the dreamtime story of *Guluyambi*, whereby a paperbark raft was used to travel across a creek and then left on its bank. The *Guluyambi*

Dreaming can now be seen as a rock in the shape of a paperbark raft, suspended in a cliff possibly 30 metres above the ground.

Bininj of Kakadu have been exposed to information regarding climate change from a variety of sources, including the Kakadu Board of Management, symposia and the media. The two consultation events conducted during the course of the project (February and April 2009) in order to seek input on Bininj values of Kakadu and views on climate change also provided information to Bininj on the findings of the study. The consultation also determined that Bininj are actively thinking about the potential impacts of climate change on their country.

During these consultations, Bininj expressed concerns about potential impacts of climate change induced saltwater intrusion and increased storm events. Concerns included increased weeds, impacts on fauna, changes to flowering and fruiting of bush tucker, increased pressure on food resources, access difficulties (e.g. to hunting areas, sacred sites) and health concerns. Overall, Bininj expressed the need for action to address climate change and highlighted the importance of communication between Bininj, researchers, policy makers and land managers.

Culture is defined as 'the patterned and learned ways of life and thought shared by a human society' (Bodley 1997 p.9). While Bininj and their culture are adaptable, it is important to understand that culture is a way of life that is dependent on the certain activities being repeated across generations. While the methods or other aspects associated with undertaking these activities may change with the changing environment, time is required to allow the cultural practices to evolve (Bourke *et al.* 2007).[29]

Collecting bush tucker, burning, telling stories, speaking in language, visiting sacred sites, connecting with the spirits of the old people and more, all rely on Bininj being able to go to the places where these activities can occur. As such, living, accessing, and working 'on country' are some of the strongest forces keeping local Bininj culture strong in Kakadu. Climate change impacts could alter this through, changes in access due to sea level rise, damage to culturally important sites caused by increase or more frequent storms, and ecological degradation causing changes in the availability of bush tucker. The following sections discuss the potential cultural impacts of climate change within the SAR catchment. The assessment has been undertaken on a catchment-wide basis as many cultural values are consistent across the landscape and cultural sensitivities of significant cultural sites means their location cannot be identified. Where non-sensitive information is known, these locations have been identified.

4.3.1 LIVING ON COUNTRY

All of the outstations in Kakadu are accessed by unsealed roads, with many outstations found in remote areas of the Park. Combined effects of sea level rise, storm surge and increased flooding could impact on the accessibility of outstations and consequently people's ability to live in these areas. At present some outstations, such as Spring Peak and Patonga Airstrip, have limited access during the wet season. Outstations found at low elevations may be prone to water inundation. At the northern end of the catchment, outstations such as Mumakala and Djirrbiyak may be particularly at risk from storm surge and resultant damage. Bininj and other stakeholders identified Djirrbiyak and Paradise Farm outstations as two locations which may also be impacted by water inundation. Further, recent observations such as the flooding of Patonga Homestead and Patonga Airstrip outstations two years ago, have concerned some Bininj as this is the first time they can remember such events. Damage to property and the safety of people living on country may also be a significant consequence of storm surge and flooding.

Rising sea levels and increasing areas of still water may lead to an increase in mosquito populations. This may increase nuisance caused by mosquitoes and the risk of mosquito-borne diseases such as Ross River Fever, Murray Valley Encephalitis and Kunjin virus which may occur in Kakadu (Northern Territory Government 2006).

4.3.2 LOOKING AFTER COUNTRY

Section 4.2 has detailed some of the potential impacts of climate change on key environmental values of Kakadu. These impacts will most likely correspond to an increase in difficulty for Bininj people to continue to undertake land management activities.

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29 Bourke *et al.* (2007) used three case studies across the Arnhem Land region to demonstrate how climatic changes during the mid to late Holocene influenced cultural change in northern Australia.

Joint management may be challenged as partners try to navigate and negotiate management responses to increased risks to values and changes to existing management issues caused by land degradation and ecosystem change. Resources (time, budget and staffing) may be stretched under increasing land management needs.

Road travel through Kakadu may be restricted through rising sea levels which may limit access to important natural resource management sites. For example, rangers noted that some billabongs previously accessed by four wheel drive are no longer accessible in this way due to rising water levels. Quad bike trails that were previously used to access certain areas are impassable now as the saline mud flats they pass over no longer completely dry out during the dry season. Traditional Owner, Violet Lawson, recalled being able to drive across freshwater areas of Red Lily Billabong in the dry season as a short cut to Leichhardt Billabong (mid 1980s). This is now impossible as the area does not completely dry out during the dry season. It is relevant to note that this change in access may also have been influenced by climatic change, seasonal variation or other structural changes associated with wetland restoration after the removal of feral animals.

4.3.3 BUSH TUCKER

One of the main concerns raised by Bininj during consultation was the potential damage to bush tucker species caused by impacts from sea level rise. A number of Bininj recounted stories of changes to flora and fauna distribution and abundance, referencing these stories as indications of potential future climate change impacts. Many groups independently shared observations of freshwater wetlands becoming increasing saline, of changes in distribution and abundance of popular bush tucker species, and of salt tolerant species replacing those with low salt tolerance. Table 4-3 summarises the observations made by Bininj and Park Rangers provided during consultation.

Table 4-3: Bininj observations of current change (2009) as indications of potential future changes to species in the SAR catchment

SPECIES	VALUE	IDENTIFIED BY	AREA OF SAR CATCHMENT	OBSERVATION
File snake	Bush tucker	Most groups	Fresh water billabongs	Moving further upstream to less salty environment. Horseshoe Billabong was noted as an example where file snake populations have decreased.
Fresh water turtle	Bush tucker	Most groups	Fresh water billabongs	Moving further upstream to less salty environment
Eleocharis	Bush tucker, important habitat	Most groups	Fresh water and brackish billabongs	Can tolerate some saltwater inundation
Magpie geese	Bush tucker	Most groups	Fresh water and brackish billabongs	Dependent on *Eleocharis* for food. Increasing water levels may impact nesting sites
Red lily	Bush tucker	Most groups	Fresh water billabongs	Saltwater kills red lilies, one of the first species to be affected
Fresh water mussels	Bush tucker	Mirrar, Murumburr clan traditional owners	Fresh water billabongs and streams	Saltwater kills freshwater mussels
Saltwater crocodiles	Bush tucker, icon species	Park staff, Jawoyn traditional owners	All marine & Fresh water ecosystems below escarpment	Moving further upstream, interacting with Fresh water crocodiles, nesting areas could be inundated through sea level rise, sex impact through temperature change
Fresh water crocodiles	Bush tucker	Park staff	All marine & Fresh water ecosystems below escarpment	Need floodplain and tidal springs to nest, interact with Saltwater crocodiles
Jabiru	Icon species	Park staff	Rookery near mouth SAR	Sea level rise could affect rookery areas
Green plum	Bush tucker	Patonga Outstation residents	Need low sandy areas to grow	Impact on low sandy areas
Black plum	Bush tucker	Patonga Outstation residents	Need low sandy areas to grow	Impact on low sandy areas
White apples	Bush tucker	Patonga Outstation residents	Need low sandy areas to grow	Impact on low sandy areas
Red apples	Bush tucker	Patonga Outstation residents	Need low sandy areas to grow	Impact on low sandy areas
Bush potato	Bush tucker	Patonga Outstation residents	Need low sandy areas to grow	Impact on low sandy areas
Eels	Bush tucker	Murumburr clan traditional owners, Patonga outstation residents, Park staff	Fresh water ecosystems	Moving further upstream

SPECIES	VALUE	IDENTIFIED BY	AREA OF SAR CATCHMENT	OBSERVATION
Sharks	Bush tucker	Murumburr clan traditional owners, Patonga outstation residents, Park staff	Saltwater ecosystems	Moving further upstream, marine species now found in previously freshwater ecosystem
Stingrays	Bush tucker	Murumburr clan traditional owners, Patonga outstation residents, Park staff	Saltwater ecosystems	Moving further upstream, marine species now found in previously freshwater ecosystem
Flounder	Bush tucker	Murumburr clan traditional owners, Jawoyn traditional owners	Saltwater ecosystems	Moving further upstream, marine species now found in previously freshwater ecosystem
Mud crabs	Bush tucker	Murumburr clan traditional owners, Patonga outstation residents, Park staff	Saltwater ecosystems	Moving further upstream, marine species now found in previously freshwater ecosystem
Goanna/water monitor	Bush tucker	Murumburr clan traditional owners, Patonga outstation residents, Park staff	Fresh water ecosystems	Could possibly be affected by saltwater
Paperbark trees	Important habitat tree & material resource	Most groups	Fresh water ecosystems	Salt intolerant
Black duck	Bush tucker	Murumburr clan traditional owners	Fresh water ecosystems	Salt kills lilies and ducks eat the lily seeds
Egrets	Common species	Murumburr clan traditional owners	Fresh water ecosystems	Prefer freshwater ecosystems
Fresh water mangroves	Important habitat tree	Murumburr clan traditional owners , Park staff	Fresh water ecosystems	Moving upstream
Pig nosed turtle	Bush tucker, threatened species	Park staff, Murumburr clan traditional owners , Patonga Outstation residents	Fresh water ecosystems	Moving upstream, losing habitat/nesting sites, temperature dependent sex determination

4.3.4 GETTING INCOME FROM COUNTRY

As discussed in Section 3.4.6, traditional owners receive income from lease and park use fees. Lease fees, determined through the lease agreement between the Director of National Parks and the Aboriginal Land Trusts, are unlikely to be impacted through climate change. However, the combined impacts of sea level rise, storm surge and flooding may indirectly impact on park use fees, should predicted impacts decrease visitor numbers.

Opportunities may also arise to increase income from country. For example, increased pressure from threats to natural resources may provide opportunities for traditional owners to develop feral animal/weed management, land rehabilitation or fire management contracting businesses.

4.3.5 LOOKING AFTER SPECIAL PLACES AND CONTINUING TRADITION

Freshwater bush tucker species raised during consultation as being of particular concern to Bininj included magpie geese, long necked turtles, file snakes and lilies. Where habitat of magpie geese or other species is impacted through sea level rise, a reduction of populations could result (refer Section 4.2), consequently impacting on the ability of local Bininj to continue to hunt these animals as bush tucker. Controlling inappropriate hunting is likely to place additional stress on Bininj and Park management as the resource decreases.

Recent incursion of marine species, including sharks, stingrays, flounder and mud crabs into previously freshwater areas was consistently raised by Bininj during consultation as a potential indication of likely future impacts. Red Lily Billabong and Yellow Water were given as examples where the occurrence of marine species has become more prominent in recent years. Traditional Owner, Bessie Coleman, noted that a flounder had been caught a long way upstream in the SAR near the Mary River Ranger Station.

Changes in the abundance and distribution of traditional food resources could have social implications for the traditional owners the SAR catchment. If major sources of bush tucker shift (for example, further upstream) then good hunting grounds may then be within different clan territories. This could impact on current social arrangements for access to, permission and the sharing of traditional food resources in accordance with customary use traditions.

Bininj believe that the natural features of the land and all that is living within it were created by the ‘First People’ (Chaloupka 1993) and this and other beliefs endow all land in Kakadu with a spiritual quality. Therefore any change to the land from sea level rise, increased or more frequent storm surge or changes in rainfall and flooding have the potential to impact on an area of cultural significance. Potential changes identified through consultation and research include:

- Sea level rise, storm surge and flooding changes may impact a site near the banks of the SAR where a creation ancestor rested on her journey.
- A women’s site near goose camp is likely to be inundated if sea levels rise.
- Dingo Dreaming, not far from Yellow Water is likely to be impacted by increased flooding, and may also be impacted through sea level rise and storm surge changes.
- Many occupation sites on the SAR floodplain with rich archaeological information could be inundated temporarily or permanently, which could have subsequent impacts on provision of insights into past cultural practices.
- Increased and more frequent storms could damage the extensive rock art galleries found throughout the escarpment and its outliers. Access to these areas could also be restricted if the dry season is shorter. Maintenance programs in these areas usually occur during the dry season and therefore the window of opportunity to complete maintenance work could be shortened.

Access to these places is imperative for looking after special places, continuing tradition and for maintaining a connection and knowledge of these places. Where access by road is limited due to climate change impacts, either the period of access may become limited or the need for alternative means of transport to reach these sites may significantly increase budget requirements.

4.3.6 LANGUAGE

Language is kept alive by its everyday use in the community. Limited access to country may impact language use, as being able to go out 'on country' and call the places, animals and plants encountered by their Aboriginal language names is the most effective activity for the passing of language and knowledge on to future generations. Often being on country encourages people to share stories in language; the loss of access to important cultural sites could lead to these opportunities being lost.

4.4 SOCIO-ECONOMIC IMPACTS

As outlined in Section 3, the key socio-economic values of the SAR catchment are based on tourism, mining, small business and vital infrastructure (including for water supply, waste water treatment, waste management and power supply, and roads). This section outlines the potential impacts of climate change on these values. The assessment of impacts has been undertaken on a catchment-wide basis as many socio-economic values occur across the catchment. However, impacts at key locations have been identified where possible.

4.4.1 MINING

4.4.1.2 SOUTH ALLIGATOR VALLEY

By both 2030 and 2070, it is likely that the rehabilitation of disused mine sites in the South Alligator Valley will have been completed. Should this work not be completed in time, the quality of the work be substandard or potential climate change impacts not be considered in current rehabilitation plans, then potential impacts may result. For example, more intense and frequent storms could cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts. This could lead to contamination of the surrounding environment, erosion, movement of silt and sediment, and additional costs in repairing rehabilitation works.

4.4.1.3 RANGER URANIUM MINE

Ranger Uranium Mine relies on access to Darwin through the SAR catchment along the Arnhem Highway. Rising sea levels, increased storm surge and increased flooding could result in closures of the Arnhem Highway for longer periods of time or on a more frequent basis. Loss of this access road has serious business implications for the mine, potentially limiting the mine's ability to operate at full capacity, and impacting on its profits and possibly on jobs. Increased rainfall could also pose challenges for the processing systems and access to the mine, and cause damage to infrastructure.

4.4.2 TOURISM

The CRC for Sustainable Tourism report (Tremblay and Boustead 2009) on climate change in Kakadu identified a number of potential impacts on tourism in the Park. While not all of these impacts are relevant to the current study, the impacts identified included:

- temperature rise leading to health risks, infrastructure and power supply strain/damage, wetland drying, reduction in saltwater crocodile populations and increased fire risk;
- an increase in the intensity of rainfall leading to flooding, damage to infrastructure and disruption to services and access;
- an increase in the intensity of cyclones leading to damage to infrastructure, higher insurance premiums and therefore higher operating costs;
- sea level rise causing saltwater to intrude into freshwater wetlands; and
- interaction with existing pressures such as weeds, feral animals and pathogens.

In terms of the climate change impacts investigated during the current study, the predominant impact to tourism is likely to be from limitations on access, in terms of the variety and number of areas that can be accessed, and the potential increase in occasions and period of time access may be cut important tourism sites. Currently access to areas such as Jim Jim Falls, Twin Falls, Maguk, Gunlom and Koolpin Gorge are limited to the dry season months of May to November. Four wheel drive vehicles are required to access Jim Jim Falls, Twin Falls and Koolpin Gorge while other sites are accessible on unsealed roads via two wheel drive. Should the dry season contract or more intense and frequent storms cause road damage, access to these sites may be limited to an even shorter season. Visitor dissatisfaction may result if tourists are unable to access well known destinations such as Jim Jim Falls, Twin Falls and Gunlom.

Where access to popular tourist attractions within the Park becomes limited, increased pressure may result for attractions that are still able to be accessed. Lobbying of Park management and traditional owners may also occur to open new areas to compensate for those that are inaccessible. If new areas are opened, potential impacts may results to ecological or cultural values of those locations and increased Park management may be required for ongoing management of these new areas.

Saltwater intrusion from sea level rise and storm surge, further exacerbated by decreased rainfall, could damage the aquatic ecosystems of Yellow Water and the South Alligator floodplain and reduce populations and sightings of icon species such as magpie geese, brolgas and jabirus. With the wetland landscape and wildlife being the focus of marketing campaigns, and with one hundred thousand visitors going on Yellow Water boat cruises every year (R. Murray 2008, pers. comm., 8 Aug.), the potential loss of the freshwater wetland landscape, including the economically important Yellow Water, could have significant impacts in terms of visitor dissatisfaction, loss of jobs and loss of revenue. Further, 'seeing wildlife' has been identified as one of the five key motives to visit Kakadu (Tremblay and Boustead 2009), and visitor satisfaction may result if less wildlife can be seen when visiting the Park. Kakadu's World Heritage listing is a major reason why people, particularly those from overseas, visit Kakadu (Director of National Parks 2001). The climate change impacts discussed in Section 4.2 and 4.3 could lead to overall degradation of the World Heritage natural and cultural values of Kakadu.

Swimming is often raised by tourism operators as an important activity in Kakadu. However, allowing swimming within the Park is a contentious issue, with saltwater crocodiles posing a risk to human life. While populations of saltwater crocodile have been increasing since the 1970s to inhabit plunge pools far upstream on the SAR (Director of National Parks 2007), Park management carry out seasonal trapping and remove crocodiles from swimming holes in an attempt to minimise the risks of swimming in these plunge pools and ban swimming in areas that are unsafe due to high levels of risk. While saltwater crocodile populations continue to increase, along with their distribution throughout the Park, increased sea level rise has the potential to propagate this impact further up the catchment. This could result in popular swimming holes such as Gubara, Jim Jim Falls, Maguk and Gunlom being closed to swimming. If swimming holes are closed this may result in decreased visitor satisfaction or negative publicity for Kakadu. Reduction in locations of safe swimming holes may also cause severe over-crowding and pressure on the natural environment and visitor services at these sites during peak times.

Tourism infrastructure may also be impacted. Tourism accommodation such as Gagadju Lodge Cooinda at Yellow Water already experiences problems with flooding during the wet season. Sea level rise, more intense and frequent storms and increased flooding may impact the resort to the extent that areas of the Gagadju Lodge Cooinda need to be closed off for long periods of time, or more frequently. However, it should be noted that this is most likely to occur when visitor numbers are low (during the off-peak season). Other tourism and recreational infrastructure could also be impacted including such as through inundation of campgrounds and walking tracks. Tourist attractions such as rock art at sites like Burrunggui (Nourlangie Rock) and Nanguluwurr may also be directly impacted through damage caused by more intense or frequent storms. The above impacts could also result in negative publicity (through messages like 'Kakadu is dangerous' or 'Kakadu is closed') which may circulate through the tourism and travel industry and may be difficult to reverse.

It should be noted that while many self-drive or individual tourist groups are likely to be affected by the impacts described above, tourism businesses (particularly those accredited under various tourism programs) often have business plans which provide measures on how to deal with changes to markets or severe weather events. This is expected to lessen the affect of the above identified climate change impacts on these tourism businesses.

The potential impacts from climate change may also provide opportunities for new, niche tourism businesses (refer Section 4.4.5) and may provide the impetus for new tourism infrastructure development within the Park of a more sustainable design and/or in more appropriate areas.

4.4.3 RECREATION

Fishing is a popular sport in Kakadu, with 20% of the Northern Territory's recreational barramundi fishing occurring in the Park (Tremblay and Boustead 2009). Fishing occurs primarily in the estuarine zone of SAR, but also through the coastal, floodplain and freshwater areas of the river. As discussed in the environmental impacts section, barramundi populations may decrease under climate change. This could damage recreational fishing values and lead to a decrease in fishing tours and independent fishing visitors. Sea level rise and an increase in salinity may also change the species targeted by fishermen, with the replacement of freshwater species by more saltwater tolerant fish species.

4.4.4 EMPLOYMENT

Tourism is a major industry and employer in Kakadu. Lower visitor numbers or a contraction of visitors into a shorter period (for example, a shorter dry season) may impact on employment in Kakadu, resulting in fewer permanent and/or seasonal jobs.

4.4.5 SMALL BUSINESS

Apart from tourism businesses, few small businesses are currently based in, or operate in the SAR catchment. However, if by 2030 and 2070 small business are operating within the catchment, they could be impacted by similar issues as may impact the tourism industry including limited/restricted access, negative publicity resulting in fewer visitors to the Park (and therefore restricted customer base) and damage to business infrastructure. However, as outlined in Sections 4.3.4 and 4.4.3, climate change impacts could also create more business opportunities, for example through development of land management contracting enterprises or niche tourism businesses.

4.4.6 HEALTH IMPACTS

Climate change factors examined in this study may lead to an increase in areas of still water and changes to the ecology of waterbodies that may potentially favour and cause an increase in mosquitoes carrying diseases. Mosquito-borne diseases may become more prevalent and the types of diseases observed within Kakadu may change. This could result in a subsequent increase in health risks. The threat of disease and nuisance caused by mosquitoes may deter visitors and impact on local residents in the Park.

Further, if power supply is impacted by climate change (refer Section 4.4.7.3), this may result in an inability to keep food chilled resulting in a decrease in food security, particularly where road access is cut for extended periods of time.

4.4.7 BUILDINGS, INFRASTRUCTURE AND SERVICES

4.4.7.1 BUILDINGS

While little development occurs in the SAR catchment, there is currently no detailed digital elevation model or guidelines on flood or storm surge levels to allow for appropriate siting of buildings. This means that there may be future developments or buildings approved in locations which may become inundated from sea level rise, storm surge or flooding under the climate change scenarios. Current developments that are inappropriately located may also experience flooding and inundation impacts, and may be increasingly impacted over time.

4.4.7.2 ROADS

Impacts to access have been discussed above in the context of cultural and socio-economic impacts. The greatest impact to roads within the SAR is likely be due to increased flooding, with road design needing to take into account significant additional quantities of water that ideally need to pass under the road (through culverts). The major roads, the Arnhem and Kakadu Highways, are likely to be relatively resilient under impacts predicted in the 2030 scenario, however, the 2070 scenario presents greater impacts which may cause extensive impacts for the road networks, particularly in the vicinity of creek or river crossings. More frequent or extended periods of inundation of roads and bridges may cause significant damage giving rise to more frequent maintenance, and potentially more frequent upgrades.

Currently road maintenance and reconstruction is undertaken on a cyclical basis, with designs using immunity levels based on the best available data at the time (refer Section 3.5.5.2). Due to the potential climate change impacts described above, design for the upgrade or construction of new roads would need to consider increased immunity levels. While these factors would create significant costs for both the NT Government and Parks Australia, it may also provide new jobs.

Road access services which provide updates are likely to become increasingly important for the public.

4.4.7.3 OTHER SERVICES

There are not likely to be any significant impacts to water supply through bores or billabongs in terms of the quantity of water supplied. However, the quality of water may be impacted and may become more saline. This may have flow on impacts in terms of:

- corrosion of equipment and vehicles washed down from the water source will be likely to deteriorate more quickly and will require replacement more frequently; and
- treatment of water will be more frequently required at more locations.

Septic systems, other water-treatment systems and waste management sites located in low-lying areas may become regularly inundated and may require increased maintenance or relocation. These impacts are likely to have resultant cost implications for organisations (i.e. Parks Australia, private enterprise).

Collection of waste from outstations and other areas is unlikely to be impacted, except through potential impacts to road access. Similarly, power supply infrastructure is unlikely to be impacted except where access is required for maintenance. Where limited access prevents the import of diesel for generators, power supply may be impacted and become less reliable.

5 Risk Assessment

Following the finalisation of the impact assessment, the risk assessment was undertaken to assess the level of risks faced under the 2030 and 2070 climate change scenarios. The risk assessment process is part of an iterative risk management process which allows continuous improvement that can easily be used within existing management frameworks (AS/NZS 4360:2004) such as those implemented by Park management within Kakadu National Park. The *Climate Change Impacts and Risk Management – A Guide for Business and Government* (Broadleaf Capital International and Marsden Jacobs Associates 2006) acknowledges that most organisations have strategies to deal with natural climatic variability as may be observed on an annual or other cyclical basis, and notes that this natural variability itself raises challenges and risks that need to be managed. However, organisations such as Parks Australia cannot continue to use assumptions based on current natural variability with regard to future climatic variability and management of values as seen from the impacts outlined in Section 4.

The risk assessment process followed in this study was based on the Australian Standard for Risk Management (AS/NZS 4360:2004) and Guideline (Broadleaf Capital International and Marsden Jacobs Associates 2006), and includes the three stages of risk identification, risk analysis and risk evaluation. The risk assessment process within the risk management framework is shown in Figure 5-1 (from AS/NZS 4360:2004).

In the context of the risk assessment, risk refers to the **risk of impact** from climate change projected using the climate change scenarios provided (refer Section 4.1.1), not the risk of climate change occurring. This process inherently recognises uncertainty in identifying the risk of impact.

The risk assessment was undertaken initially by the study team, and then subsequently within a workshop setting with key stakeholders and Bininj. The risk identification and risk analysis undertaken prior to the workshop was reviewed by the workshop participants in a process which verified and provided feedback on these two stages. The findings from each of the stages are presented in the following sections.

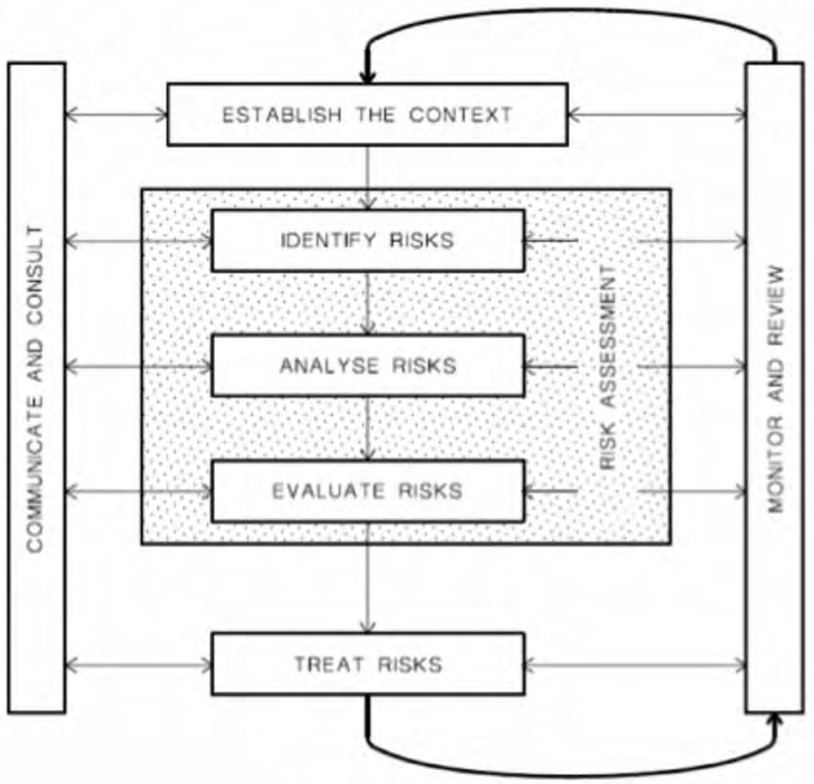

Figure 5-1: Risk Assessment within Risk Management Process (AS/NZS 4630:2004)

5.1 INITIAL RISK ASSESSMENT

5.1.1 RISK IDENTIFICATION

Through the technical and scientific research undertaken through the literature review, consultation, computer modelling and impact assessment, the risks of climate change impacts on the ecological, cultural and socio-economic values of the SAR were defined. The focus of the study was on adverse impacts on the values, with any beneficial impacts being noted within the impact assessment. For the initial risk analysis, 35 risks were identified (refer Table 5-1).

Table 5-1: List of initial risks identified

VALUES	RISKS TO VALUES	
Ecological Values	**E1**	Decrease in freshwater flora extent
	E2	Loss of existing magpie goose feeding areas
	E3	Loss of pig-nose turtle habitat
	E4	Decrease in potodramous fish
	E5	Decrease in freshwater crocodile abundance
	E6	Decrease in monsoon rainforest
	E7	Decrease in woodland extent
	E8	Reduced saltwater crocodile reproductive success
	E9	Reduced barramundi reproductive success
	E10	Decreased yellow chat abundance
	E11	Reduced estuarine/marine flora and fauna abundance
Cultural Values	**C1**	Road access may be cut to bush tucker, sacred sites, archaeological sites and outstations
	C2	More intense and frequent storms cause damage to archaeological sites, sacred sites and outstations
	C3	Water inundation causes damage to archaeological sites, sacred sites and outstations
	C4	Increasing salinity damages bush tucker availability
	C5	Land degradation makes it difficult to care for country and harvest resources
Socio-economic Values (including mining, small business, tourism, general infrastructure/ services)	**S1**	More intense and frequent storms cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts in the South Alligator Valley
	S2	Road access may be cut to min and rehabilitation sites in the South Alligator Valley
	S3	More intense and frequent storms cause damage to infrastructure at Koongarra (hypothetical – if mine becomes operational)
	S4	Road access may be cut to small businesses operating in the SAR
	S5	More intense and frequent storms cause damage to small business infrastructure
	S6	Road access may be cut to major tourism attractions including Jim Jim Falls, Twin Falls, Maguk, Gunlom, Koolpin Gorge
	S7	Saltwater intrusion damages tourist attraction (Yellow Water, South Alligator floodplain) and icon species (Brolga, magpie goose, jabiru)
	S8	More intense and frequent storms cause damage to infrastructure, tourism attractions (e.g. art sites), restrict visitor days and create bad publicity
	S9	Saltwater crocodiles expand range into traditional swimming billabongs
	S10	Degradation of World Heritage natural and cultural values (from storm damage and saltwater intrusion)

VALUES	RISKS TO VALUES	
	S11	Increase in mosquito populations increases health risk and nuisance (for visitors and residents)
	S12	Damage to fish nurseries and populations damages recreational fishing (tours and independent) values
	S13	Increased salinity changes target species for fishermen
	S14	Lower visitor numbers causes a decrease in permanent / seasonal jobs
	S15	Increase in usage of existing accessible areas and disturbance of new areas to meet tourism demand
	S16	Increase in infrastructure that is no longer 'fit for purpose'
Planning and Regulation	**P1**	Increase in developments being approved/built in inappropriate places due to lack of available information, and triggers in legislation
	P2	Increase in current approved/lawful development becoming inappropriate
	P3	Increase in requirements for ongoing management and planning resources within KNP

5.1.2 RISK ANALYSIS

The initial risk analysis phase involved:

- identification of the existing measures that are implemented to, or act to control the risks and manage the values;
- definition of the success criteria for the values of the SAR catchment; and
- determination of the likelihood based on the predicted response of the system to increased sea level rise, increased storm surge related to changes in intensity and frequency of cyclones, and changes in rainfall.

5.1.2.1 IDENTIFICATION OF EXISTING CONTROLS

A broad range of controls for management of the ecological, cultural and socio-economic values of the SAR catchment are currently being implemented or act to manage the values within the catchment. For the purposes of considering the following risk assessment process, reference was made to the controls identified in Section 3.6.

While these existing measures may not be implemented specifically for the purpose of managing values in the face of climate change, some of these controls also assist in managing the risks of climate change on the ecological, cultural and socio-economic values.

5.1.2.2 CONSEQUENCE

The consequence is the outcome of the event and is considered in relation to the achievement of objectives. For the purposes of this assessment, consequence was defined according to two different sets of success criteria, or objectives:

1. The aims within the Key Result Areas (KRAs) of the *Kakadu National Park Management Plan 2007–2014.* The KRAs from the Management Plan are:
    - KRA1: Natural heritage management
    - KRA 2: Cultural heritage management
    - KRA 3: Joint management
    - KRA 4: Visitor management
    - KRA 5: Stakeholders and partnerships
    - KRA 6: Business management

The full list of aims under each KRA are identified in Appendix L.

2. A predicted level of impact on an identified value (refer Section 4). Where aims from the KRAs were not directly applicable to the risk being assessed, a predicted level of impact on the values was applied.

The consequence scale identified through this process is presented in Table 5-2.

Table 5-2: Consequence scale

CONSEQUENCE SCALE	SUCCESS CRITERIA	
	BASED ON AIMS FOR KRAS IN KNP MANAGEMENT PLAN	*BASED ON IMPACT TO VALUE*
Insignificant	No impediment to achievement of aim	No impact to value
Minor	Isolated instances where impediment to achievement of aim	Minor / short-term impact to value
Moderate	Regular occasions where impediment to achievement of aim	Moderate / medium-term impact to value
Major	Continuous impediment to achievement of aim	Major / long-term impact to value
Catastrophic	Aim cannot be achieved	Permanent and irreversible impact to value

Note that while the Broadleaf Capital International and Marsden Jacobs Associates document (2006) uses an approach that provides a specific consequence for each rating within the consequence scale, this approach was not considered feasible for the current study due to the large number of success criteria. Generalised 'ratings' were determined for each level in the consequence scale for both sets of criteria; an approach which considered the methodology in Broadleaf Capital International and Marsden Jacobs Associates (2006).

5.1.2.3 LIKELIHOOD

Likelihood refers to the 'conditional' likelihood; that is the likelihood of the risk of impact occurring is assessed as if the climate change scenario was going to happen (Broadleaf Capital International and Marsden Jacobs Associates 2006). In this context, this required an assessment of whether the identified risk is considered likely to occur based on the predicted response of the system to the modelled climate change scenarios (refer Section 4). Therefore, the likelihood of a specific risk arising may differ depending on which scenario is being considered.

Table 5-3 (Broadleaf Capital International and Marsden Jacobs Associates 2006) was used as a guide to determine the likelihood of physical process impacts within the five zones of the SAR catchment under the various climate change scenarios, based on the results of the computer modelling and impact assessment. These are illustrated in Figure 5-2. These were combined with the likelihood of predicted response for the other values to determine likelihood for each risk.

Table 5-3: Likelihood

RATING	RECURRENT RISKS	SINGLE EVENTS
Almost certain	Could occur several times per year	More likely than not – probability greater than 50%
Likely	May arise about once per year	As likely as not – 50/50 chance
Possible	May arise about once in ten years	Less likely than not but still appreciable – probability less than 50% but still quite high
Unlikely	May arise about once in ten years to 25 years	Unlikely but not negligible – probability low but noticeably greater than zero
Rare	Unlikely during the next 25 years	Negligible – probability very small, close to zero

Source: Broadleaf Capital International and Marsden Jacobs Associates 2006

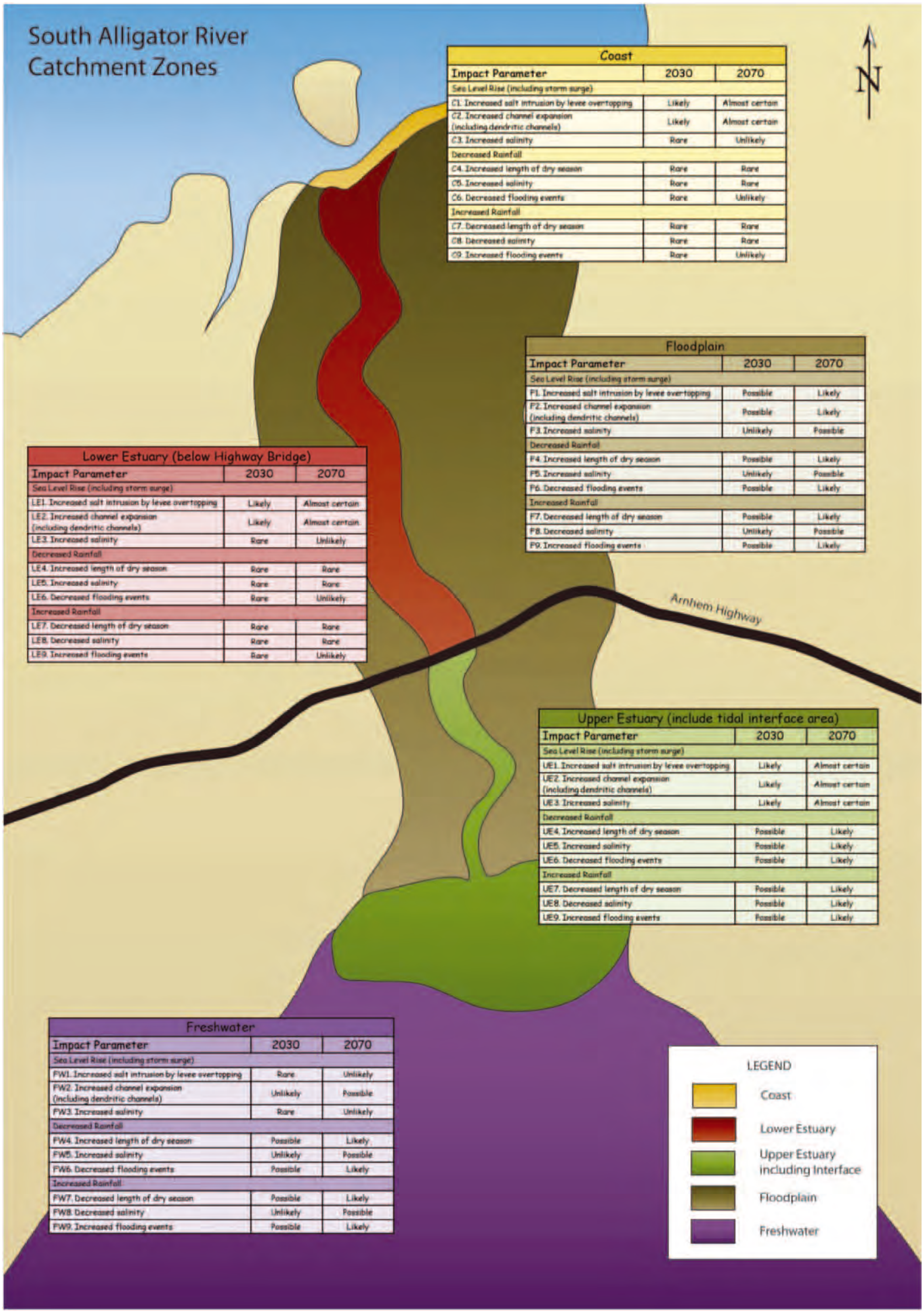

Figure 5-2: Likelihood of physical process impacts within SAR catchment zones

5.1.2.4 ANALYSIS

Information from Section 3 and Section 4 of this report, and initial consultation with Bininj and stakeholders was then used to determine the likelihood and consequence of the 35 ecological, cultural and socio-economic risks determined during the risk identification phase (identified in Section 5.1.1) using the risk matrix shown in Figure 5-3.

	INSIGNIFICANT	MINOR	MODERATE	MAJOR	CATASTROPHIC
Almost Certain	medium	medium	high	extreme	extreme
Likely	low	medium	high	high	extreme
Possible	low	medium	medium	high	high
Unlikely	low	low	medium	medium	medium
Rare	low	low	low	low	medium

Figure 5-3: Risk matrix

For each risk, the assessment considered:

- The four combinations of scenarios:
  - 2030 SLR + storm surge, and decreased rainfall;
  - 2030 SLR + storm surge, and increased rainfall;
  - 2070 SLR + storm surge, and decreased rainfall; and
  - 2070 SLR + storm surge, and increased rainfall.
- The zone of the SAR catchment.

In this way, multiple analyses were undertaken for each identified risk. For each risk, the SAR zones with the highest risk level was entered into the initial 'risk register' for use at the workshop (refer Appendix M). In some cases, the risk analysis results for a number of SAR zones was shown, particularly where differences in results for the zones was considered important for determination of potential adaptation options. This resulted in a total of 40 risk analyses being presented in the register. The distribution of risk levels for the various analyses is shown in Table 5-4.

Note that risk evaluation was not undertaken in the initial stage by the study team.

Table 5-4: Number of risks levels for low, medium, high and extreme for risk analyses presented to the workshop

	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO		2070 SLR (700 MM) + 2070 CYCLONE SCENARIO	
	DECR. RAINFALL	INCR. RAINFALL	DECR. RAINFALL	INCR. RAINFALL
Low	11	5	6	4
Medium	21	30	16	10
High	8	5	15	23
Extreme	0	0	3	3

5.2 REVISED RISK ASSESSMENT

5.2.1 RISK IDENTIFICATION

Following presentation of the identified risks workshop participants provided feedback, identifying three new risks and amending the wording of some risks previously identified. Table 5-5 shows the revised list of risks following the workshop (additional risks in purple, amended risks in blue).

Table 5-5: List of revised risks identified

VALUES	RISKS TO VALUES	
Ecological Values	**E1**	Decrease in freshwater flora extent
	E2	Loss of existing magpie goose feeding areas
	E3	Loss of pig-nose turtle habitat
	E4	Decrease in potodramous fish
	E5	Decrease in freshwater crocodile abundance
	E6	Decrease in monsoon rainforest
	E7	Decrease in woodland extent
	E8	Reduced saltwater crocodile reproductive success
	E9	Reduced barramundi reproductive success
	E10	Decreased yellow chat abundance
	E11	Reduced estuarine/marine flora and fauna abundance
	E12	Loss of existing magpie goose nesting area
	E13	Reduction in frog abundance
Cultural Values	**C1**	Road access may be increasingly cut to bush tucker, sacred sites, archaeological sites and outstations
	C2	More intense and frequent storms cause damage to archaeological sites, sacred sites and outstations
	C3	Water inundation causes damage to archaeological sites, sacred sites and outstations
	C4	SLR decreases bush tucker availability
	C5	Land degradation makes it difficult to care for country and harvest resources
Socio-economic Values (including mining, small business, tourism, general infrastructure/ services)	**S1**	More intense and frequent storms cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts in the South Alligator Valley
	S2	Road access may be cut to mine and rehabilitation sites in the South Alligator Valley
	S3	More intense and frequent storms cause damage to infrastructure at Koongarra (hypothetical – if mine becomes operational)
	S4	Road access may be cut to small businesses operating in the SAR
	S5	More intense and frequent storms cause damage to small business infrastructure
	S6	Increased incidence of road access being cut to major tourism attractions including Jim Jim Falls, Twin Falls, Maguk, Gunlom, Koolpin Gorge
	S7	Saltwater intrusion damages tourist attraction (Yellow Water, South Alligator floodplain) and icon species (Brolga, magpie goose, jabiru)
	S8	More intense and frequent storms cause damage to infrastructure, tourism attractions (e.g. art sites), restrict visitor days and create bad publicity
	S9	Increased incidence of saltwater crocodiles preventing access to swimming billabongs (visitor dissatisfaction)

VALUES	RISKS TO VALUES	
	S10	Degradation of World Heritage natural and cultural values (from storm damage and saltwater intrusion)
	S11	Increase in mosquito populations increases health risk and nuisance (for visitors and residents)
	S12	Damage to fish nurseries and populations damages recreational fishing (tours and independent) values
	S13	Increased salinity changes target species for fishermen
	S14	Lower visitor numbers causes a decrease in permanent / seasonal jobs
	S15	Increase in usage of existing accessible areas and disturbance of new areas to meet tourism demand
	S16	Infrastructure increasingly unfit for purpose
	S17	Road access and product transport is cut to Ranger Mine
Planning and Regulation	**P1**	Increase in developments being approved/built in inappropriate places due to lack of available information, and triggers in legislation
	P2	Increase in current approved/lawful development becoming inappropriate
	P3	Increase in requirements for ongoing management and planning resources within KNP

Note: Additional risks in purple, amended risks in blue.

5.2.2 RISK ANALYSIS

For each risk in the risk register, workshop participants reviewed existing controls, consequence and likelihood (as shown in Section 5.1), verifying or amending risk levels. Risk analyses were also undertaken for the three new risks. The revised risk analyses are shown in the risk register in Table 5-7. The detailed assessment of each risk is shown in Appendix N. Table 5-6 summarises the distribution of 43 risk analyses from the revised risk register.[30]

On review of the risk levels outside of the workshop process, the Northern Territory Government expressed the view that a number of the risk levels should be higher than had been assessed by the workshop participants. However, to maintain the integrity of the workshop risk assessment process, it was determined to retain risk levels resulting from the workshop.

Table 5-6: Number of risks levels for low, medium, high and extreme for risk analyses following review by workshop participants

	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO		2070 SLR (700 MM) + 2070 CYCLONE SCENARIO	
	DECR. RAINFALL	INCR. RAINFALL	DECR. RAINFALL	INCR. RAINFALL
Low	12	7	7	5
Medium	21	30	16	12
High	10	6	15	22
Extreme	0	0	5	4

30 This includes a number of risks that are analysed across different catchment zones.

5.2.3 RISK EVALUATION

According to the AS/NZS 4360:2004 Risk Management, the risk evaluation process within risk assessment is to assist the decision-making process through deciding which risks need treatment and assigning treatment priorities. Consistent with this process, it was planned that workshop participants would prioritise the risks to be treated prior to the development of adaptation options.

However, at the workshop there was consensus among workshop participants to move ahead and treat all the risks. It was decided that due to the relatively small number of risks, the entire list of risks should be used for risk treatment (i.e. determination of adaptation options). This was determined as appropriate because one of the objectives of the study was to determine a range of adaptation options for assessment in Stage Six of the study. Proceeding on this basis was considered to provide the broadest range of options for later consideration and assessment by management organisations.

5.3 SUMMARY OF RISK ASSESSMENT PROCESS

The following points summarise the risk assessment process.

- Higher level risks were determined for 2070 scenarios than 2030 scenarios, both before and after the workshop due to either a higher level likelihood or consequence being determined for risk for the 2070 scenarios.
- At 2030, over 50% of risks were considered low or medium, but at 2070 over 50% of risks were considered high or extreme.
- Prior to the workshop, extreme risk levels were determined for three cultural and one tourism risk. Following the workshop, two ecological, two cultural and one tourism risk were considered extreme.
- Fifty per cent of the extreme risks were mostly attributed to impacts to magpie geese habitat and flow on risks to bush tucker availability.
- Extreme risks were determined through a consideration of sea level rise, storm surge related to more intense and frequent cyclones and rainfall changes.

Table 5-7: Revised risk register

RISK AND RISK ID		SAR CATCHMENT ZONE WITH HIGHEST RISK LEVEL	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO — DECR. RAINFALL		
			LIKELIHOOD	CONSEQUENCE	RISK LEVEL
ECOLOGICAL VALUES					
E1	Decrease in freshwater flora extent	Floodplain	Possible	Major	High
		Upper Estuary	Almost certain	Moderate	High
		Freshwater	Unlikely	Moderate	Medium
E2	Loss of existing magpie goose feeding areas	Floodplain	Possible	Major	High
E3	Loss of pig-nosed turtle habitat	Freshwater	Unlikely	Minor	Low
E4	Decrease in potodramous fish	Floodplain	Possible	Moderate	Medium
E5	Decrease in freshwater crocodile abundance	Upper Estuary	Likely	Moderate	High
		Floodplain	Possible	Moderate	Medium
		Freshwater	Unlikely	Minor	Low
E6	Decrease in monsoon rainforest extent	Floodplain	Possible	Moderate	Medium
E7	Decrease in woodland extent	Floodplain, Freshwater	Rare	Minor	Low
E8	Reduced saltwater crocodile reproductive success	Lower Estuary, Upper Estuary	Possible	Minor	Medium
E9	Reduced barramundi reproductive success	Floodplain, Freshwater	Possible	Moderate	Medium*
E10	Decreased yellow chat abundance	Floodplain, Upper Estuary	Possible	Moderate	Medium
E11	Reduced estuarine/marine flora and fauna abundance	Lower Estuary, Upper Estuary, Coastal	Unlikely	Insignificant	Low
E12	Loss of existing magpie goose nesting area	Floodplain	Possible	Major	High
E13	Reduction in frog abundance	Floodplain	Possible	Major	High
CULTURAL VALUES					
C1	Road access may be increasingly cut to bush tucker, sacred sites, archaeological sites and outstations	Upper Estuary	Likely	Major	High
C2	More intense and frequent storms cause damage to archaeological sites, sacred sites and outstations	Predominantly catchment-wide	Possible	Major	High
C3	Water inundation damages archaeological sites, sacred sites and outstations	Floodplain	Possible	Moderate	Medium
C4	Sea level rise decreases bush tucker availability	Upper Estuary	Likely	Moderate	High
C5	Land degradation makes it difficult to care for country and harvest resources		Possible	Moderate	Medium
SOCIO-ECONOMIC VALUES					
Mining					
S1	More intense and frequent storms cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts in the South Alligator Valley	Freshwater	Rare	Moderate	Low
S2	Road access may be cut to mine and rehabilitation sites in the South Alligator Valley	Freshwater	Rare	Insignificant	Low
S3	More intense and frequent storms cause damage to infrastructure at Koongarra (should mine become operational- note this is purely hypothetical)	Freshwater	Possible	Moderate	Medium

	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO			2070 SLR (700 MM) + 2070 CYCLONE SCENARIO					
	INCR. RAINFALL			DECR. RAINFALL			INCR. RAINFALL		
	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL
	Possible	Moderate	Medium	Likely	Major	High	Likely	Moderate	High
	Likely	Moderate	High	Almost certain	Moderate	High	Almost certain	Moderate	High
	Rare	Moderate	Low	Possible	Moderate	Medium	Unlikely	Moderate	Medium
	Possible	Moderate	Medium	Almost certain	Major	Extreme	Almost certain	Major	Extreme
	Rare	Minor	Low	Possible	Minor	Medium	Unlikely	Minor	Low
	Possible	Moderate	Medium	Likely	Major	High	Likely	Major	High
	Likely	Moderate	High	Almost certain	Moderate	High	Almost certain	Moderate	High
	Possible	Minor	Medium	Likely	Moderate	High	Likely	Minor	Medium
	Rare	Minor	Low	Possible	Minor	Medium	Unlikely	Minor	Low
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Moderate	High
	Rare	Minor	Low	Unlikely	Minor	Low	Unlikely	Minor	Low
	Possible	Minor	Medium	Possible	Moderate	Medium	Likely	Major	High**
	Possible	Minor	Medium	Likely	Moderate	High*	Likely	Minor	Medium
	Possible	Minor	Medium	Likely	Moderate	High	Likely	Minor	Medium
	Unlikely	Insignificant	Low	Possible	Insignificant	Low	Possible	Insignificant	Low
	Possible	Major	High	Almost certain	Major	Extreme	Almost certain	Major	Extreme
	Possible	Moderate	Medium	Likely	Major	High	Likely	Moderate	High
	Likely	Major	High	Almost certain	Major	Extreme	Almost certain	Major	Extreme
	Possible	Major	High	Possible	Major	High	Likely	Major	High
	Possible	Moderate	Medium	Likely	Major	High	Likely	Major	High
	Possible	Moderate	Medium	Almost certain	Major	Extreme	Possible	Major	High
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Moderate	High
	Rare	Moderate	Low	Rare	Moderate	Low	Rare	Moderate	Low
	Possible	Moderate	Medium	Rare	Insignificant	Low	Likely	Moderate	High
	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Moderate	High

RISK AND RISK ID		SAR CATCHMENT ZONE WITH HIGHEST RISK LEVEL	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO		
			DECR. RAINFALL		
			LIKELI-HOOD	CONSEQUENCE	RISK LEVEL
S17	Road access and product transport is cut to Ranger Mine	Lower Estuary	Rare	Major	Low
Small Business					
S4	Road access may be cut to small businesses operating in the SAR	Upper Estuary	Likely	Minor	Medium
S5	More intense and frequent storms cause damage to small business infrastructure	Predominantly catchment-wide	Possible	Minor	Medium
Tourism					
S6	Increased incidence of road access being cut to major tourism attractions including Jim Jim Falls, Twin Falls, Maguk, Gunlom, Koolpin Gorge		Unlikely	Moderate	Medium
S7	Saltwater intrusion damages tourist attraction (Yellow Water, South Alligator floodplain) and icon species (Brolga, magpie goose, jabiru)	Upper Estuary	Likely	Major	High
S8	More intense and frequent storms cause damage to infrastructure, tourism attractions (eg art sites), restrict visitor days, threaten visitor safety and create bad publicity		Possible	Moderate	Medium
S9	Increased incidence of crocodiles preventing access to swimming billabongs (visitor dissatisfaction)		Unlikely	Moderate	Medium
S10	Degradation of World Heritage natural and cultural values (from storm damage and saltwater intrusion)		Unlikely	Moderate	Medium
S11	Increase in mosquito populations increase health risk and nuisance (for visitors and residents)		Possible	Moderate	Medium
S12	Damage to fish nurseries and populations damages recreational fishing (tours & independent) values		Possible	Moderate	Medium
S13	Increased salinity changes target species for fishermen		Possible	Minor	Medium
S14	Lower visitor numbers causes a decrease in permanent / seasonal jobs		Possible	Moderate	Medium
S15	Increase in usage of existing accessible areas and disturbance of new areas to meet the tourism demand		Possible	Minor	Medium
General Infrastructure / Services					
S16	Infrastructure increasingly unfit for purpose	Floodplain, Lower Estuary	Unlikely	Insignificant	Low
		Freshwater	Rare	Insignificant	Low
PLANNING AND REGULATION					
P1	Increase in developments being approved/built in inappropriate places due to lack of available information, and triggers in legislation		Unlikely	Minor	Low
P2	Increase in current approved/lawful development becoming inappropriate		Rare	Insignificant	Low
P3	Increase in requirements for ongoing management and planning resources within KNP		Unlikely	Insignificant	Low

	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO			2070 SLR (700 MM) + 2070 CYCLONE SCENARIO					
	INCR. RAINFALL			DECR. RAINFALL			INCR. RAINFALL		
	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL
	Rare	Major	Low	Unlikely	Major	Medium	Unlikely	Major	Medium
	Likely	Minor	Medium	Almost certain	Minor	Medium	Almost certain	Minor	Medium
	Possible	Minor	Medium	Possible	Minor	Medium	Likely	Minor	Medium
	Possible	Moderate	Medium	Unlikely	Moderate	Medium	Likely	Moderate	High
	Likely	Major	High	Almost certain	Major	Extreme	Almost Certain	Major	Extreme
	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Major	High
	Unlikely	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium
	Unlikely	Moderate	Medium	Unlikely	Moderate	Medium	Unlikely	Moderate	Medium
	Possible	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Moderate	High
	Possible	Minor	Medium	Possible	Minor	Medium	Possible	Minor	Medium
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Major	High
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Major	High
	Possible	Minor	Medium	Unlikely	Insignificant	Low	Likely	Moderate	High
	Possible	Minor	Medium	Rare	Insignificant	Low	Likely	Moderate	High
	Unlikely	Moderate	Medium	Possible	Minor	Medium	Possible	Moderate	Medium
	Possible	Moderate	Medium	Unlikely	Minor	Low	Likely	Moderate	High
	Possible	Moderate	Medium	Possible	Minor	Medium	Likely	Moderate	High

5.4 ACCEPTABILITY OF CURRENT RISK LEVEL

As identified previously, during the consultation process some Bininj and stakeholders were of the view that climate change impacts were already occurring within the catchment. Given this, it was determined necessary to undertake an exercise as part of the workshop to try to determine the current level of acceptability for each risk in the above risk analysis. For this process, a simple continuum model was developed, and at the workshop, participants identified the progression of risks based on this continuum of acceptability (Figure 5-4). The results indicated that workshop participants believed the level of risk for all risks identified was currently in the acceptable zone of the continuum.

The study team also planned to use the exercise as a means to workshop potential indicators and quantitative limits of acceptable change to monitor potential changes in levels of identified risks. However, due to the lack of data underpinning the modelling and subsequent impact assessment, it was determined that only qualitative indicators could be used. Through consultation it became apparent that due to current restrictions in resources, and also an understanding that beginning to gather this information was highly important, the indicators focussed on the aspects Bininj and Rangers observed while working or living on country that could be easily tracked over time. Study team members also contributed to this process. Some possible, simple observation-based indicators that can be used to track each of the risks are outlined in Table 5-8. The indicators presented in the table are based on the findings outlined in Section 3 and Section 4 of this report. It is envisaged that these would be reviewed over time to determine success of the indicators, and potentially new indicators added to the list.

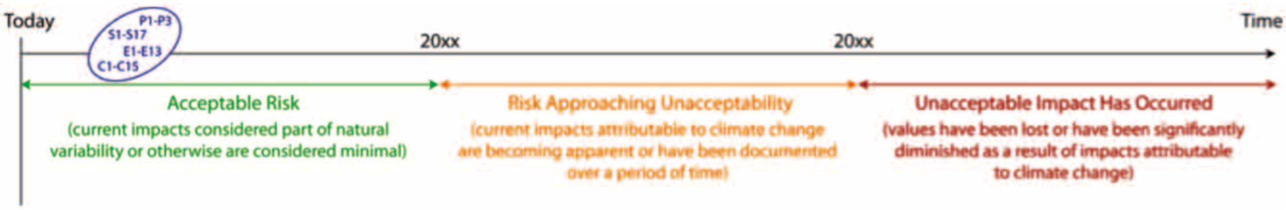

Figure 5-4: Position of risks along the 'continuum of acceptability'

Table 5-8: Acceptability of current risk level and potential qualitative indicators

RISKS TO VALUES		POTENTIAL INDICATORS FOR IMPLEMENTATION OF RELEVANT ADAPTATION OPTIONS
E1	Decrease in freshwater flora extent	• Number of freshwater flora species decreases OR • Number of locations dominated by freshwater species decreases OR • Area of individual locations dominated by freshwater species decreases
E2	Loss of existing magpie goose feeding areas	• Number of magpie geese decreases OR • Number of locations magpie geese feed in decreases OR • Area of individual locations at which magpie geese feed decreases OR • Length of magpie geese feeding within a location decreases OR • Timing of magpie geese movements changes
E3	Loss of pig-nose turtle habitat	• Number of pig-nosed turtles (or nests) decreases OR • Number of locations at which pig-nosed turtles (or nests) are observed decreases
E4	Decrease in potodramous fish	• Number of fish species decreases OR • Abundance of individual fish species decreases OR • Number of locations at which fish are observed decreases OR • Area of individual locations at which fish are observed decreases
E5	Decrease in freshwater crocodile abundance	• Number of freshwater crocodiles (or nests) decreases OR • Number of locations at which freshwater crocodiles (or nests) are observed decreases OR • Area of individual locations at which freshwater crocodiles are observed decreases
E6	Decrease in monsoon rainforest	• Number of monsoon rainforest flora species decreases OR • Number of monsoon rainforest inhabitant fauna species decreases OR • Abundance of monsoon rainforest inhabitant fauna species decreases OR • Number of locations of monsoon rainforest decreases OR • Area of individual monsoon rainforest locations decreases
E7	Decrease in woodland extent	• Number of woodland flora species decreases OR • Number of woodland inhabitant fauna species decreases OR • Abundance of woodland inhabitant fauna species decreases OR • Area of woodland decreases
E8	Reduced saltwater crocodile reproductive success	• Number of saltwater crocodiles (especially juveniles) decreases OR • Number of saltwater crocodile nests decreases OR • Number of locations at which saltwater crocodile nest decreases OR • Area of individual locations at which saltwater crocodiles nest decreases
E9	Reduced barramundi reproductive success	• Abundance of barramundi decreases OR • Number of locations at which barramundi occur decreases • Area of individual locations at which barramundi occur decreases
E10	Decreased yellow chat abundance	• Sightings of yellow chat decrease OR • Number of locations at which yellow chat are observed decreases OR • Area of individual locations at which yellow chat are observed decreases

RISKS TO VALUES		POTENTIAL INDICATORS FOR IMPLEMENTATION OF RELEVANT ADAPTATION OPTIONS
E11	Reduced estuarine/marine flora and fauna abundance	• Number of estuarine/marine flora and fauna species decreases OR • Abundance of individual estuarine/marine flora and fauna species decreases OR • Number of locations at which estuarine/marine flora and fauna species are observed decreases OR • Area of individual locations of estuarine/marine flora and fauna habitats decreases
E12	Loss of existing magpie goose nesting area	• Number of magpie geese decreases OR • Number of magpie goose nests decreases OR • Number of locations suitable for magpie goose nesting decreases OR • Area of individual locations for magpie goose nesting decreases OR • Timing of magpie goose nesting changes
E13	Reduction in frog abundance	• Number of frog species observed decreases OR • Abundance of individual frog species decreases OR • Number of locations at which frogs are observed decreases OR • Area of individual locations at which frogs are observed decreases
C1	Road access may be increasingly cut to bush tucker, sacred sites, archaeological sites and outstations	• Frequency of cut roads increases OR • Duration of cut roads increases OR • Number of cut roads increases OR • Frequency of required maintenance or repair work increases OR • Severity of required maintenance or repair work increases
C2	More intense and frequent storms cause damage to archaeological sites, sacred sites and outstations	• Number of damaged sites increases OR • Frequency of damage to sites increases OR • Severity of damage to sites increases
C3	Water inundation causes damage to archaeological sites, sacred sites and outstations	• Number of damaged sites increases OR • Frequency of damage to sites increases OR • Severity of damage to sites increases
C4	SLR decreases bush tucker availability	• Number of available bush tucker species decreases OR • Abundance of individual bush tucker species decreases OR • Number of locations at which bush tucker is available decreases OR • Period of availability of bush tucker species decreases
C5	Land degradation makes it difficult to care for country and harvest resources	• Frequency of inaccessibility to sites increases OR • Number of inaccessible sites increases
S1	More intense and frequent storms cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts in the South Alligator Valley	• Frequency of damage increases OR • Severity of damage increases
S2	Road access may be cut to mine and rehabilitation sites in the South Alligator Valley	• Frequency of cut roads increases OR • Duration of cut roads increases OR • Number of cut roads increases OR • Frequency of required maintenance or repair work increases OR • Severity of required maintenance or repair work increases

RISKS TO VALUES		POTENTIAL INDICATORS FOR IMPLEMENTATION OF RELEVANT ADAPTATION OPTIONS
S3	More intense and frequent storms cause damage to infrastructure at Koongarra (hypothetical –if mine becomes operational)	• Frequency of damage increases OR • Severity of damage increases
S4	Road access may be cut to small businesses operating in the SAR	• Frequency of cut roads increases OR • Duration of cut roads increases OR • Number of cut roads increases OR • Frequency of required maintenance or repair work increases OR • Severity of required maintenance or repair work increases
S5	More intense and frequent storms cause damage to small business infrastructure	• Frequency of required maintenance or repair work increases OR • Severity of damage increases OR • Number of small businesses damaged increases OR • Number of days small businesses operate decreases
S6	Increased incidence of road access being cut to major tourism attractions including Jim Jim Falls, Twin Falls, Maguk, Gunlom, Koolpin Gorge	• Frequency of cut roads increases OR • Duration of cut roads increases OR • Number of cut roads increases OR • Frequency of required maintenance or repair work increases OR • Severity of required maintenance or repair work increases
S7	Saltwater intrusion damages tourist attraction (Yellow Water, South Alligator floodplain) and icon species (brolga, magpie goose, jabiru)	• Number of visitors decreases OR • Frequency of tours operating decreases OR • Abundance of individual icon species decreases OR • Number of locations at which icon species are observed decreases
S8	More intense and frequent storms cause damage to infrastructure, tourism attractions (e.g. art sites), restrict visitor days and create bad publicity	• Number of visitors decreases OR • Frequency of required infrastructure repair increases OR • Severity of required infrastructure repair increases OR • Number of specific tourism attraction sites decreases OR • Number of negative media reports increases
S9	Increased incidence of saltwater crocodiles preventing access to swimming billabongs (visitor dissatisfaction)	• Frequency of crocodile sightings at swimming sites increases OR • Number of designated swimming sites decreases OR • Number of saltwater crocodile incidents increases
S10	Degradation of World Heritage natural and cultural values (from storm damage and saltwater intrusion)	• Refer indicators for E1-12 and C1-5
S11	Increase in mosquito populations increases health risk and nuisance (for visitors and residents)	• Number of cases of mosquito-borne diseases increases OR • Introduction of new tropical diseases
S12	Damage to fish nurseries and populations damages recreational fishing (tours and independent) values	• Number of fish species decreases OR • Abundance of individual fish species decreases OR • Number of locations suitable for fishing decreases OR • Number of visitors decreases OR • Number of tours decreases
S13	Increased salinity changes target species for fishermen	• Abundance of current target species decreases OR • New species are targeted

RISKS TO VALUES		POTENTIAL INDICATORS FOR IMPLEMENTATION OF RELEVANT ADAPTATION OPTIONS
S14	Lower visitor numbers causes a decrease in permanent / seasonal jobs	• Visitor numbers decreases OR • Number of jobs decreases
S15	Increase in usage of existing accessible areas and disturbance of new areas to meet tourism demand	• Frequency of required maintenance at existing areas increases OR • New areas requiring maintenance due to tourism disturbance are identified
S16	Infrastructure increasingly unfit for purpose	• Frequency of maintenance or repair works required for infrastructure increased OR • Increased health and safety incidents due to unfit infrastructure
S17	Road access and product transport is cut to Ranger Mine	• Frequency of cut roads increases OR • Duration of cut roads increases OR • Frequency of required maintenance or repair work increases OR • Extent of required maintenance or repair work increases
P1	Increase in developments being approved/built in inappropriate places due to lack of available information, and triggers in legislation	• Frequency of damage to developments increases OR • Number of developments damaged increases OR • Duration of damage to developments increases
P2	Increase in current approved/ lawful development becoming inappropriate	• Frequency of damage to developments increases OR • Number of developments damaged increases OR • Duration of damage to developments increases
P3	Increase in requirements for ongoing management and planning resources within KNP	• Funds and/or staff required for management and planning increases

6 Identification and Initial Assessment of Adaptation Options

6.1 BACKGROUND

In the context of treating risks to ecological, cultural and socio-economic values from climate change impacts, ‘adaptation’ refers to the *‘adjustments in response to climate change that lead to a reduction in risks or a realisation of benefits’* (SMEC Australia 2007). Adaptation to climate change requires adaptive management over the long term, in which options are re-assessed and implemented over time as climate change impacts eventuate.

Following identification and assessment of the risk that climate change poses, and the relative significance of each of those risks (Broadleaf Capital International and Marsden Jacobs Associates 2006), the formulation of appropriate adaptation options was required to treat the risks. Adaptation options were based on reviews of existing information and consultation with Bininj and key stakeholders. Evaluation of each of the options was also undertaken to determine potential barriers or constraints to implementation and to identify appropriate implementing and partnering agencies.

The adaptation option identification and initial assessment process was guided by Broadleaf Capital International and Marsden Jacobs Associates (2006) and further developed using the conceptual approach shown in Figure 6-1. The process is further defined in Sections 6.2 and 6.3.

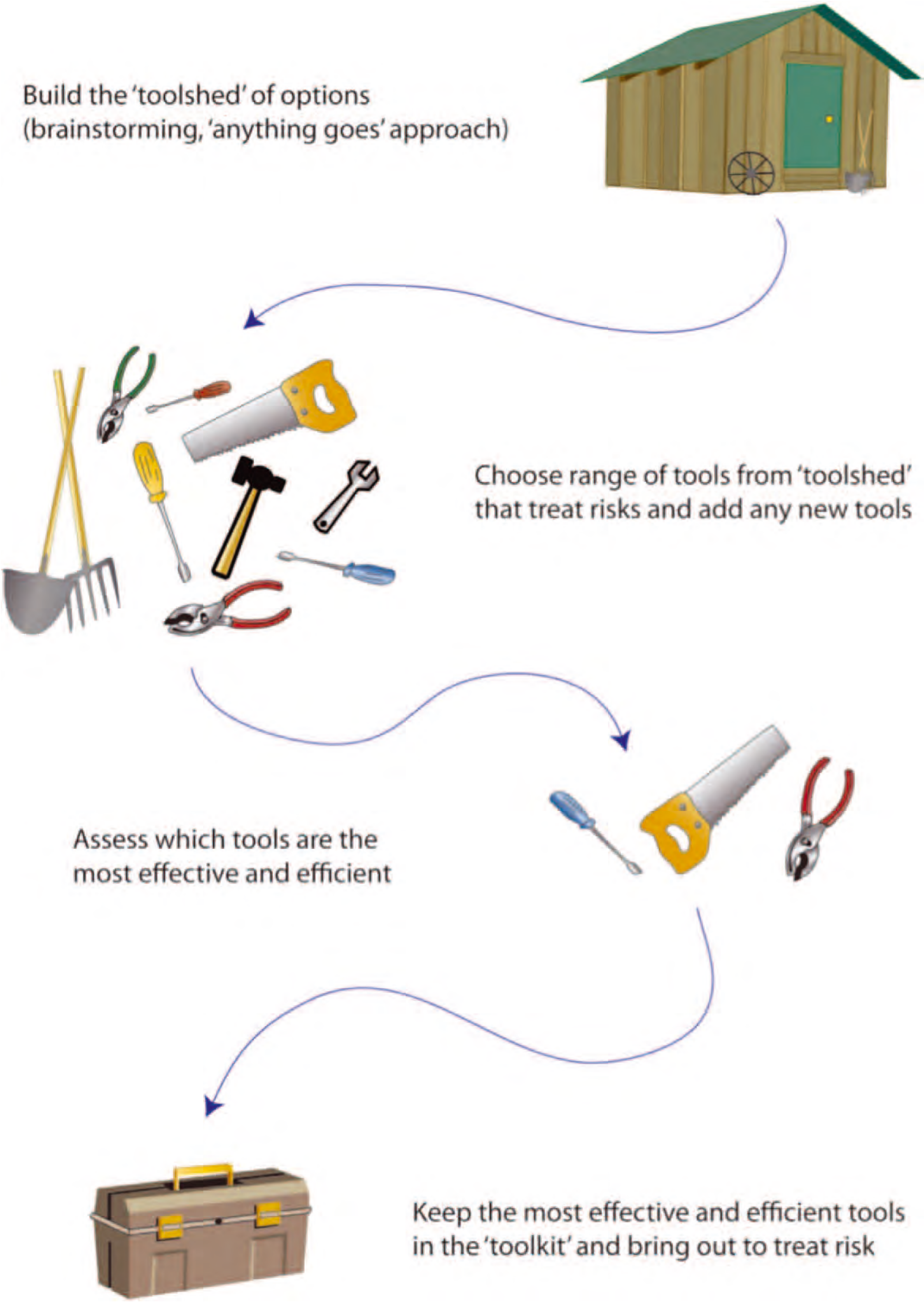

Figure 6-1: Toolshed/Toolkit Approach – adaptation options identification and initial assessment process

6.2 IDENTIFICATION OF ADAPTATION OPTIONS

6.2.1 DEVELOPMENT OF THE 'TOOLSHED'

Following initial consultation with Bininj and stakeholders (February 2009) and the preliminary risk assessment by the study team, a list of adaptation options were developed. The criterion used for inclusion of an option in the list was that it had been mentioned during consultation with Bininj or stakeholders or identified by the study team. Consideration was also given to adaptation options developed and/or implemented to treat climate change risks in other natural World Heritage Areas (UNESCO 2007).

To ensure a range of options was considered, the adaptation options were arranged according to the Broadleaf Capital International and Marsden Jacobs Associates (2006) categorisation of types of climate change risk treatments into:

- **spread risk** – insurance and diversification strategies;
- **structural and technological** – prevent effects through engineering solutions and changed practices;
- **regulatory and institutional** – prevent or mitigate effects through revised regulations and planning;
- **avoidance** – avoid or exploit changes in risk;
- **research** – research to improve understanding of relationship between climate change and risk; and
- **educational and behavioural** – educate and inform stakeholders about the risks of climate change.

A total of 80 options were compiled in this list (provided in Appendix O) and the list was provided to workshop participants for use as a 'tool shed'.

6.2.2 CHOOSING THE TOOLS THAT TREAT THE RISKS

Using the revised risk register (Table 57) and the adaptation options 'toolshed', workshop participants identified potential adaptation options to address each risk. Options identified in the workshop session were not limited to those from the 'toolshed', but participants used the 'toolshed' options or identified additional options as appropriate. Appendix P provides the list of adaptation options identified for each risk. These were consolidated in to the list of options in Table 6-1.

On review of the identified adaptation options outside of the workshop process, the Northern Territory Government expressed the view that a number of adaptation options should be removed, added or amended.[31] However, to maintain the integrity of the workshop risk assessment process, it was determined to retain the list of adaptation options identified by workshop participants.

31 For example, the Northern Territory Government requested:

a) The option to close current sites be removed and be replaced with an option considering the alteration of access arrangements at site adversely impacted by climate change.

b) Actions such as screening visitors would not be considered a viable option. Instead the NT Government considered that continued prevention of the *Aedes aegypti* in the Northern Territory as a more appropriate response.

c) Options considering recreational fisheries should also consider harvesting by indigenous fishers and commercial operators at the mouth of the SAR, resulting in an option such as "Implement additional management measures to ensure the overall harvest by recreational, fishing tour operator, commercial and indigenous fishers is maintained at ecologically sustainable levels".

Table 6-1: Consolidated list of adaptation options

ADAPTATION OPTION	EXPLANATION / DETAILS
Review of the location of past mining facilities in the upper SAR catchment and determination of priority rehabilitation areas	Past mining facilities would include extractive industry, small mines, and exploration areas
Current mine rehabilitation projects modeled for use at other sites	
Any future mine planning to take into account sea level rise	Note: comment during workshop that this is not something that would need to be done in the immediate future, and not considered a big issue at the moment.
Development and implementation of business models and plans to ensure businesses (small business and tourism) are adapted to climate change – for current and future businesses	Would need to deal with issues such as: how to get greater yield out of same or less period of time (shorter periods of access) or less visitors; identification of suitable locations, identification of facility design; building flexibility into operations to deal with extreme events and change from climate change impacts; how to manage customer/visitor expectations; how to adapt the product offered, and in the case of a major event, how to identify and implement a “Plan B” business (ie. following a disastrous event).
Centralised (NT) Government planning to provide NT-wide risk mapping	This would include floods, storm surge, mosquito maps (ie diff mosquitoes in different locations).
Build resilience into current road access	This would involve raising roads and replacing associated infrastructure (e.g. replace culvert with bridge), upgrading of accesses (e.g. Pine Creek access) to build in an ‘acceptable’ level of resilience. This level would need to be determined.
All weather road access to be developed	Raising roads sufficient to provide all weather access; may need to look for new road corridors
Modelling studies to be undertaken to determine required levels for future road upgrades	This would involve data collection and review of standards
Identify current key sites (tourism, cultural) to which access should be maintained and, where applicable, consider issues of capacity in these areas	e.g. provide additional infrastructure in areas which begin to experience high level visitation
Identify new tourism opportunities (ie. different type of visitor experience)	Note this does not refer to new sites
Change access to current sites and identify new sites for tourism to maintain the current experience	e.g. if all freshwater areas where visitors can swim have saltwater crocodiles due to expansion of habitat from SLR, these sites should be closed. Where possible, new sites for swimming should be identified.
Use of alternative forms of transport to and within areas where access lost due to SLR/ flooding	e.g. hovercraft, aquabus, helicopter, plane (FIFO arrangements), for mining, tourism and small business
Upgrade communication strategy	To provide up-to-date information on conditions and assist management of visitor expectation (e.g. why can’t swim in Park anymore). Include review of current method of information dissemination regarding alternate routes for travel and tourist routes/weather conditions/water levels/site damage/etc. Manage PR associated with extreme events, provide information on why sites/roads are closed (not just road closed sign).

ADAPTATION OPTION	EXPLANATION / DETAILS
Replicate sites and/or create 'Living Museum'	These sites / museum would be a place people could visit to see the species, landscapes and culture that have been significantly impacted (e.g. this would include gathering a representative collection of artefacts from archaeological site on the floodplain (stone tools etc) for storage and viewing in appropriate facilities by visitors and as a reference collection).
Review and update Incident Response Plan to consider climate change related events and ensure stakeholders are aware of additional responsibilities	This would include issues such as identifying safe areas from flash flooding and cyclone shelter locations, reviewing any existing safety thresholds e.g. water supply, temp, rainfall, etc), and identifying mechanisms to determine additional thresholds for safety. The review of the plan would also need to ensure consideration of people throughout the Park (including tourist areas and outstations).
Manage crocodile numbers	Could be through provision of additional resources to Parks for the management of crocodiles (e.g. include number of people-days for crocodile surveys etc).
Provision of crocodile-proof cages for swimming	Put crocodile-proof cages in freshwater areas (e.g. base of popular waterfalls) so people can continue to swim following crocodiles moving into the area.
Provide alternative areas for people to swim around the Park	e.g. safe areas at top of falls during dry season, swimming pools.
Provide education in the Park, Jabiru, local schools, and the visitor centre regarding climate change impacts	e.g. ecological, cultural, and health and safety. This could include provision of information regarding: potential impacts and relevance of climate change in the context of natural variability of the area, saltwater crocodiles moving into new areas and the reasons for this; new entomological threats/species (e.g. potential species of mosquitoes or sandflies, associated diseases for each species, preferred habitat for each species), appropriate clothing for protection from mosquitoes and time of day different species are prevalent. Parks and Council would need to work collaboratively to produce information and education material, and may need to liaise with government or research institutes external to the Park.
Determine World Heritage natural and cultural values (from storm water damage and saltwater intrusion) most exposed	
Identify and implement planned protection of priority sites through structural means	e.g. construction of barrages on dendritic channels, levee construction at highway bridge; offshore barrier to reduce saltwater inflow volumes, weirs to create flood storage that can be used for environmental flow release. This would require a staged process including: preliminary feasibility studies; small scale trials/pilot projects if shown to be feasible; detailed planning and environmental impact assessment studies; construction and maintenance of structure; and monitoring of effectiveness of structure
Identify and implement appropriate planning measures for the prevention of introduction of tropical diseases in the Park	Specific measures considered included: (a) increase research into appropriate drugs for prevention and management of potential new diseases (b) provision of free insect repellent at visitor centre (c) screening of visitors to prevent introduction of disease vectors (this may not be practical).
Better regulate and enforce recreational fishing	Sub-options raised included: introduce recreational fishing licences, limit number of licences available, catch and release requirements on all fishing, and incorporate tagging for scientific research purposes; reduce bag and size limits, further restrict access of recreational fishers. More generally, this option should involve management measures that ensure the overall harvest by recreational, fishing tour operator, commercial and indigenous fishers is maintained at ecologically sustainable levels.

ADAPTATION OPTION	EXPLANATION / DETAILS
Prohibit recreational fishing in the Park	No other native species allowed to be taken from the Park, so also prevent take of any native fish
Impose additional conditions on permits for commercial activities undertaken within the Park	e.g. for fish competitions or tours
employment opportunities for transitioning people into new employment not impacted by climate change and provide appropriate training	This may include, for example, approaching the mining industry for seasonal jobs to offset losses in other industries
Investigate best practice management of infrastructure which becomes unfit for purpose due to climate change impacts	Including retrofitting, relocation, etc
Investigate planning requirements and climate change response policy across the NT and ensure consistency and implementation within Parks	
Manage the mine and Park facilities to improve self-sufficiency	e.g. provide alternative energy for the mine and Park where required due to inability to maintain current infrastructure
Identify key sites (refugia) and values (ecological, cultural) and examine opportunities to spread risk	This should be based on: (a) Review existing information; (b) Undertake gap analysis to identify needs for further data collection; (c) Collect data to in-fill gaps (e.g. in consultation with TOs, undertake research on, and documentation of archaeological sites (middens etc which can provide historical information on diet, culture, environment etc))
Assess risks to key ecological sites	Through collection of topographic data and development of DEM; refresh Bureau of Meteorology data set for incorporation into the Building code and Australian Rainfall and Runoff guidelines; undertaking hydraulic modelling; undertaking ecological response modelling
Build resilience in ecological refugia	This could involve weed control, implementation of measures to protect remaining populations of high value species through habitat protection and sustainable harvest, implementation of a captive breeding program for high value species and to provide food source for TOs and species of recreational fishing importance, strict enforcement of regulations to manage impacts at high priority sites, visitor management to manage impacts at high priority sites, adequate rock art maintenance program is in place (in consultation with TOs) to optimise resilience of rock art against threats such as weathering, storm damage, exposure, rain damage, animal rubbing and visitor impacts

6.3 INITIAL ASSESSMENT OF ADAPTATION OPTIONS

Adapting to Climate Change: A Queensland Local Government Guide (LGAQ 2007) identifies that when considering adaptation measures, there is a hierarchy of measures reflecting time, cost and effort that are useful in assessing and identifying the most appropriate responses to potential impacts from climate change. Generally this equates to low level risks requiring measures that are less costly and easier to implement (i.e. they can potentially be implemented in an organisation's current management framework), while higher level risks require measures that are more costly, harder to implement and may require the development of new systems or processes or require assessment prior to implementation.

6.3.1 WORKSHOP ASSESSMENT OF ADAPTATION OPTIONS

To provide an initial assessment of the identified adaptation option, workshop participants were asked to determine the most effective and efficient options (from those identified in Section 6.2.2) to be undertaken in response to the identified risks. The assessment framework implemented required workshop participants to:

- identify the risks each of the options addressed (i.e. each option may have an effect on or treat multiple risks);
- consider the barriers to implementation of adaptation actions including budget required, whether a policy change or introduction of legislation was required, and whether it was considered acceptable to the community. These barriers were rated high (H), medium (M) or low (L); and
- identify potential lead organisations for implementation of the adaptation option, and any potential partners or leveraging.

The assessment by workshop participants was undertaken on the unconsolidated list of adaptation options. These results were revisited and merged to provide results for an initial assessment of the consolidated list of adaptation options. The results of the assessment are shown in Table 6-2.

6.3.2 TIME SCALE FOR IMPLEMENTATION OF ADAPTATION OPTIONS

While it was not part of the scope of this study to develop an adaptation action plan with distinct timeframes for implementation of adaptation options, acknowledging the underlying uncertainty about when potential climate change impacts may occur, implementation of adaptation actions should be considered with some reference to a time scale. That is, the adaptation option should not be implemented too early to cause unnecessary costs a long time prior to the manifestation of the risk, but should not be left too late so that it is ineffective in treating the identified risk.

Typically, those options considered to be 'no regrets' or 'low-hanging fruit' (i.e. options that are easy to put in place, at low cost) can be implemented within the period of acceptable risk. Other options may be implemented as the risks move toward the period of unacceptability (refer Table 6-2). The potential observation-based indicators identified in Table 5-8 can, over time, provide this information but it is important to start collecting this information now. Thresholds or trigger levels for the indicators have not been developed within the current study. However, with Bininj and Rangers out on country beginning to track these observations over time, it is likely that determination of some basic indicators for identification of appropriate timing of adaptation option implementation can be developed.

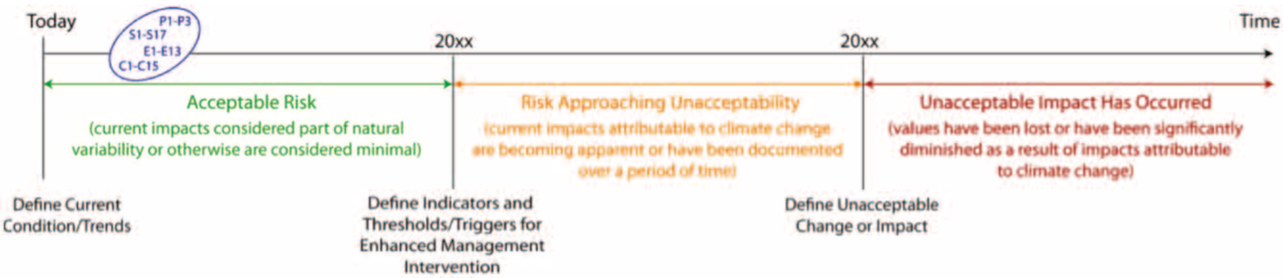

Figure 6-2: Timescale for implementation of adaptation options using thresholds/triggers related to acceptability of risk

Table 6-2: Initial assessment of adaptation options

ADAPTATION OPTIONS	RISKS ADDRESSED BY OPTION	EVALUATION OF CONSTRAINTS/BARRIERS			POTENTIAL LEAD AGENT FOR IMPLEMENTATION	POTENTIAL PARTNERS/ LEVERAGING
		FINANCIAL/ BUDGETARY	LEGISLATIVE/ POLICY CHANGE	COMMUNITY ACCEPTABILITY		
Review of the location of past mining facilities in the upper SAR catchment and determination of priority rehabilitation areas	S1, S2	Low	No	High	NT Govt	KNP
Current mine rehabilitation projects modelled for use at other sites	S1	Medium	No	High	Fed Govt	NT Govt
Future mine planning to take into account sea level rise	S3	Low	No	Low	Fed Govt	TOs
Development and implementation of business models and plans to ensure businesses (small business and tourism) are adapted to climate change – for current and future businesses	S4, S5, S6, S7, S8, S9, S12, S14, S15, S16	Medium	No	Medium	Individual businesses	Fed Govt, NT Govt
Centralised (NT) Government planning to provide NT-wide risk mapping	E1, E2, E3, E6, E7, E11, E12, C1, C2, C3, C4, C5, S1, S2, S3, S17, S4, S5, S6, S7, S8, S10, S13, S15, S16, P1, P2	High	No	High	NT Govt[33]	Fed Govt, KNP
Build resilience into current road access	C1, S2, S4, S6, S17	High	No	High	NT Govt, Parks Aus[34]	Parks Aus, KNP
All weather road access to be developed	C1, S2, S4, S6, S17	High	No	High	NT Govt[35]	Parks Aus, KNP
Modelling studies to be undertaken to determine required levels for future road upgrades	C1, S2, S4, S6, S17	Medium	No			
Identify current key sites (tourism, cultural) to which access should be maintained and, where applicable, consider issues of capacity in these areas	C1, S4, S6	Low	No	High	KNP	NT Govt, Fed Govt, TOs, Eriss
Identify new tourism opportunities (ie. different type of visitor experience)	S6, S7, S8, S12, S14, S15	Low	No	Medium	KNP[36]	NT Govt, Fed Govt

32 While proposed as NT Government, at the time of writing jurisdictional risk mapping was a subject of discussion between States/Territories and the Australian Government through the COAG Coastal Adaptation Group. Responsibility may fall to other organisations.

33 The lead agent will vary depending on the road (refer 3.5.5.2).

34 As above.

35 Following the workshop, the Northern Territory Government advised additional potential lead agents may include business, traditional owners and Tourism NT.

ADAPTATION OPTIONS	RISKS ADDRESSED BY OPTION	EVALUATION OF CONSTRAINTS/BARRIERS			POTENTIAL LEAD AGENT FOR IMPLEMENTATION	POTENTIAL PARTNERS/ LEVERAGING
		FINANCIAL/ BUDGETARY	LEGISLATIVE/ POLICY CHANGE	COMMUNITY ACCEPTABILITY		
Change access to current sites and identify new sites for tourism to maintain the current experience	S15	Low	No	Medium	KNP	NT Govt, Fed Govt
Use of alternative forms of transport to and within areas where access lost due to SLR/flooding	C1, S2, S4, S6	Medium	No	Medium	KNP	TOs, Fed Govt
Upgrade communication strategy	S6, S7, S8, S9, S10, S11, S12, S13, S14, S15	High	No	Medium	KNP	NT Govt
Replicate sites and/or create 'Living Museum'	C1, C2, C3, S8, S14	Medium	No	Medium	KNP, TOs	NT Govt, Parks Aus
Review and update Incident Response Plan to consider climate change related events and ensure stakeholders are aware of additional responsibilities	S6, S8, P3	Low	Yes	High	NT Govt, KNP, Police, SES	TOs
Manage crocodile numbers	S9	Medium	No	Medium	KNP	NT Govt, Parks Aus
Provision of crocodile-proof cages for swimming	S9	Medium	No	Low	KNP	NT Govt, Parks Aus
Provide alternative areas for people to swim around the Park	S9	Low[37]	No	Medium	KNP	NT Govt, Parks Aus
Provide education in the Park, Jabiru, local schools, and the visitor centre regarding climate change impacts	S14	Low	No	High	KNP	NT Govt, Parks Aus
Determine World Heritage natural and cultural criteria values (from storm water damage and saltwater intrusion) most exposed	S10	Low	No	High	Fed Govt	NT Govt, Parks Aus, KNP
Identify and implement planned protection of key sites through structural means	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, C1, C2, C3, C4, C5	High	No	Medium	KNP	NT Govt, Fed Govt
Identify and implement appropriate planning measures for the prevention of introduction of tropical diseases in the Park	S11	Medium	No	High	NT Govt	Fed Govt, KNP

36 The budget could potentially be higher if access to alternative swimming areas required new roads to be built.

37 'Medium' was determined from low acceptability amongst recreational fishers and high acceptability amongst land managers and conservationists.

ADAPTATION OPTIONS	RISKS ADDRESSED BY OPTION	EVALUATION OF CONSTRAINTS/BARRIERS			POTENTIAL LEAD AGENT FOR IMPLEMENTATION	POTENTIAL PARTNERS/ LEVERAGING
		FINANCIAL/ BUDGETARY	LEGISLATIVE/ POLICY CHANGE	COMMUNITY ACCEPTABILITY		
Better regulate and enforce recreational fishing	E4, E9	Low	No	High	KNP	NT Govt, Parks Aus
Prohibit recreational fishing in the Park	E4, E9	Low	Yes	Medium[38]	KNP	NT Govt, Parks Aus
Impose additional conditions on permits for commercial activities undertaken within the Park (e.g. commercial fishing tours)	S12	Low	No	Low	KNP	NT Govt, Parks Aus
Investigate employment opportunities for transitioning people into new employment not impacted by climate change and provide appropriate training	S14	Medium	No	Medium	KNP	NT Govt, Fed Govt
Investigate best practice management of infrastructure which becomes unfit for purpose due to climate change impacts	S16	Medium	No	High	KNP	NT Govt, Fed Govt
Investigate planning requirements and climate change response policy across the NT and ensure consistency and implementation within Parks	P1, P2, P3	Low	Yes	Medium	NT Govt, KNP	Fed Govt
Improve the mine and Park facilities to improve self-sufficiency	S1, S5, S8, S16	Medium	No	High	KNP, Fed Govt	NT Govt
Identify key sites (refugia) and values (ecological, cultural) and examine opportunities to spread risk	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13, C1, C2, C3, C4, C5	Low	No	High	KNP	TOs, NT Gov, Fed Gov, Eriss
Assess risks to key ecological sites	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13	Medium	No	High	Fed Govt	KNP, NT Govt
Build resilience in ecological refugia	E1, E2, E3, E4, E5, E6, E7, E8, E9, E10, E11, E12, E13	High	No	High	KNP	NT Govt, Parks Aus

7 Assessment of Implementation of Adaptation Options vs 'Do Nothing' Approach

The final stage in the assessment process was an economic assessment of the adaptation options developed (Section 6) to treat the risks of climate change impacts on the values of the SAR catchment. The assessment aimed to determine the magnitude of the costs, the magnitude and range of benefits, if the expected benefits of the option are at least equal to the costs and the willingness of the community to pay for implementation of the option.

While recognising the economic drivers of the region (in particular, tourism and mining) as vital for the future economic prosperity of the region, there are non-use values for society which are not readily valued but are important to preserve. These include the maintenance of biodiversity and culturally significant sites, as well as the existence and philanthropic value. Due to time and resource constraints these non-use values are not considered in this economic assessment.[38]

7.1 ASSESSMENT METHODOLOGY

Adaptation options developed (Section 6) can be classified as actions which secure or protect the natural capital (including valuable ecosystems and resources) from the impacts of climate change, or as actions which accept that climate change is inevitable and attempt to adapt to the likely changes. For the most part, the financial cost of implementing adaptation options is, at best, an estimate. The benefits are equally uncertain. However, there are likely to be substantial trade-offs associated with the choice of option.

7.1.1 RATIONALE FOR ADOPTING A MULTIPLE CRITERIA ANALYSIS APPROACH

For the purpose of this analysis, an assessment approach was required that was sufficiently comprehensive to facilitate the incorporation of information from multiple disciplines, specifically, biophysical, economic and social/cultural. The approach was also required to be sufficiently transparent to demonstrate the magnitude of the trade-offs and sufficiently flexible to enable the inclusion of both quantitative and qualitative information. The Resource Assessment Commission (Resource Assessment Commission 1992) describes decisions, particularly where environmental impacts are involved, as complex, with the need *'to integrate a large amount of factual information (economic, strategic, social, environmental) with value judgments, public opinion and policy and management goals.'* Multiple criteria analysis (MCA) is described as improving the quality of the decision, and providing justification for any recommended actions.

Environmental decision-making is characterised by complexity, uncertainty, multiple and conflicting outcomes and often by irreversibility. In these situations, conventional approaches to decision-making, for example cost-benefit analysis (CBA), which evaluate projects or programs based on the sole criterion of economic efficiency have been criticised as masking both the complexity of environmental impacts and the trade-offs between competing objectives. MCA offers a process approach to decision-making during which information, of a scientific as well as social and economic nature, about the problem to be addressed is integrated in the evaluation exercise to prioritise action.

MCA is promoted in the literature (Robinson 2000; Froger and Munda 1998) as offering a number of positive features for project evaluation, not specifically provided in standard evaluation techniques such as CBA. These include: the opportunity to incorporate information about intangible impacts as well as impacts that are difficult to measure in monetary terms within decision making; providing a formal process to address the different needs of multiple groups of stakeholders; and providing a process whereby the decision to accept or reject a course of action is made through a process of information discovery.

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38 Note that De Groot *et al.* (2008) have made considerable progress in the valuation of all ecosystem functions, including non-use values, for an adjacent catchment area.

7.1.2 THE MULTIPLE CRITERIA ANALYSIS PROCESS

The MCA process is best described as a series of steps with information elaborating the problem and options to address the problem.

7.1.2.1 THE DO-NOTHING OPTION

The expected performance of options, as for any economic evaluation technique, requires a 'do-nothing' option to be established against which the performance of proposed options can be measured. For this analysis the 'do-nothing' option is described as the 2030 scenario. It has been assumed for the purposes of this assessment that if climate change impacts are being observed by 2030, significant and ongoing review of risks and analysis of options will have provided the opportunity to undertake an assessment against the 2070 scenario.

7.1.2.2 THE OPTIONS

For the purpose of this assessment, it will be assumed that the overarching objective for all the proposed options is to maintain the existing and future use values from the catchment. Many of the options can be regarded as 'no regrets' options such that, even in the absence of reliable data about the impacts of climate change, these options would have only positive benefits to the catchment if implemented.

For the purpose of this MCA, the options have been restructured and grouped as addressing the risks to mining, tourism, health and safety, ecology, and transport and communication. The adaptation options provided for this assessment were those outlined in Table 6-1. The options used in the MCA are outlined in Table 7-1.

Table 7-1: Adaptation options used for the MCA

OPTIONS		EXPLANATION / DETAILS
Tourism		
Adaptation	Promote new tourism opportunities at existing sites	Identify new tourism opportunities at existing sites. This option would require promotion of a different type of visitor experience. For example, tourism could be promoted where visitors come to see the changes in delicate ecosystems resulting from climate change impacts.
	Open new tourism sites	Close current sites and identify new sites for tourism to maintain the current experience. For example, if freshwater areas where visitors can swim have increased the number of saltwater crocodiles due to expansion of habitat from sea level rise, these sites should be closed and new sites should be opened where the same or similar amenity values can be experienced.
	Replicate sites and/or create 'Living Museum'	These sites / museum would be a place people could visit to see the species, landscapes and culture that have been lost (e.g. this would include gathering a representative collection of artifacts from archaeological sites on the floodplain (stone tools etc) for storage and viewing in appropriate facilities by visitors and used as a reference collection).
Secure Existing Sites	Maintain access to priority sites (sites of ecological and cultural significance)	
	Maintain infrastructure at priority sites to meet capacity requirements and self sufficiency	Identify current key sites (tourism, cultural) to which access should be maintained and, where applicable, consider issues of capacity in these areas and provide additional infrastructure in areas which begin to experience high level visitation
	Manage crocodile numbers and minimise human contact	This action is comprised of a number of sub options: • *Manage crocodile numbers* • Through provision of additional resources to Parks for the management of crocodiles (e.g. include number of people-days for crocodile surveys etc). • *Provision of crocodile-proof cages for swimming* • Put crocodile-proof cages in freshwater areas (e.g. base of popular waterfalls) so people can continue to swim following crocodiles moving into the area. • *Provide alternative areas for people to swim around the Park* • e.g. safe areas at top of falls during dry season, swimming pools.
	Maintain World Heritage listing	Determine World Heritage natural and cultural values most exposed (from storm water damage and saltwater intrusion)
Mining		
Adaptation	Rehabilitate past mining facilities	Review of the location of past mining facilities in the upper SAR catchment and undertake rehabilitation of priority areas. This action would be designed to prevent contamination of waterways from tailings dams and disused mine sites.

OPTIONS		EXPLANATION / DETAILS
Secure Potential Mine Sites	Upgrade infrastructure to improve self sufficiency at proposed mine sites	This action would ensure access to and infrastructure at any proposed mining site was maintained in situations of sea level rise and storm events. Water and power supplies would need to be secured and seepage into the mine would require substantial draining pumping capacity. This option is likely to require structural intervention including drainage work around mine sites. It should be noted that the upgrade and securing of potential mine sites would be included in the mine planning and the cost would be incurred by the mine rather than by the government.
Health and Safety – These options are closely associated with options to maintain levels of tourism in the Park.		
Adaptation	Prevent introduction of tropical diseases	Identify and implement appropriate planning measures for the prevention of introduction of tropical diseases in the Park. This action may include measures such as NT Health Department planning for screening of visitors to prevent introduction of disease vectors, increased research into appropriate drugs for prevention and management of potential new diseases and their availability in Australia (e.g. anti-malarials and treatment options).
	Develop incidence response plan	Review and update Incident Response Plan to consider climate change related events and ensure stakeholders are aware of additional responsibilities. This would include issues such as identifying safe areas from flash flooding and cyclone shelter locations, reviewing any existing safety thresholds e.g. water supply, temp, rainfall, etc), and identifying mechanisms to determine additional thresholds for safety. The review of the plan would also need to ensure consideration of people throughout the Park (including tourist areas and outstations).
	Upgrade safety communication	Upgrade communication strategy to provide up-to-date information on conditions and assist management of visitor expectation (e.g. why can't swim in Park). Include review of current method of information dissemination regarding alternate routes for travel and tourist routes/weather conditions/water levels/site damage/etc. Manage public relations associated with providing information and warnings about extreme events. This communication strategy needs to be designed to be credible to visitors and carry a message of urgency underpinned by enforcement if required.
Ecology		
Adaptation	Educate visitors and residents and businesses about climate change and reduction of footprint in critical areas	This action requires credible information to be disseminated to local residents, businesses and visitors about the vulnerability of the Park to climate change. Businesses likely to be adversely affected by climate change could require planning assistance to diversify or restructure their business. Limits to visitors in critical and vulnerable areas might be required.
	Manage extractive uses for the Park	Better regulate and enforce recreational fishing- options raised included: introduce recreational fishing licences, limit number of licences available, catch and release requirements on all fishing, and incorporate tagging for scientific research purposes; reduce bag and size limits, further restrict access of recreational fishers, impose additional conditions on permits for commercial activities undertaken within the Park. More generally, this option should involve management measures which ensure that the overall harvest by recreational, fishing tour operator, commercial and indigenous fishers is maintained at ecologically sustainable levels.

OPTIONS		EXPLANATION / DETAILS
Adaptation	Manage key ecological sites to build resilience	• *Identify key sites (refugia) and values (ecological, cultural)* and examine opportunities to spread risk. This should be based on: (a) Review existing information; (b) Undertake gap analysis to identify needs for further data collection; (c) Collect data to in-fill gaps (e.g. in consultation with TOs, undertake research on, and documentation of archaeological sites (middens etc which can provide historical information on diet, culture, environment etc)) • *Assess risks to key ecological sites* – through collection of topographic data and development of DEM; refresh Bureau of Meteorology data set for incorporation into the Building code and Australian Rainfall and Runoff guidelines; undertaking hydraulic modelling; undertaking ecological response modelling • *Build resilience in ecological refugia* – this could involve weed control, implementation of measures to protect remaining populations of high value species through habitat protection and sustainable harvest, implementation of a captive breeding program for high value species and to provide food source for TOs and species of recreational fishing importance, strict enforcement of regulations to manage impacts at high priority sites, visitor management to manage impacts at high priority sites, adequate rock art maintenance program is in place (in consultation with TOs) to optimise resilience of rock art against threats such as weathering, storm damage, exposure, rain damage, animal rubbing and visitor impacts
Secure Existing Sites	Structural protection of priority sites	Identify and implement planned protection of priority sites through structural means e.g. construction of barrages on dendritic channels, levee construction at highway bridge; offshore barrier to reduce saltwater inflow volumes, weirs to create flood storage that can be used for environmental flow release. This would require a staged process including: preliminary feasibility studies; small scale trials/pilot projects if shown to be feasible; detailed planning and environmental impact assessment studies; construction and maintenance of structure; and monitoring of effectiveness of structure.
Transport and Communication		
Secure Existing Sites	Develop alternative forms of transport into and within Park	Use of alternative forms of transport to and within areas where access lost due to climate change impacts. This would include hovercraft, aquabus, helicopter, plane (FIFO arrangements) for mining, tourism and small business
	Construct all weather road access	Build resilience into current road access – involving raising roads and replacing associated infrastructure (e.g. replace culvert with bridge), upgrading of accesses (e.g. Pine Creek access) to build in an 'acceptable' level of resilience. This level would need to be determined. May need to look for new road corridors.
Research		
	Development of DEM	
	Mapping critical habitat areas	
	Mapping cultural, archaeological sites	
	Upgrade Bureau of Meteorology data	
	Undertake hydraulic modelling	
	Undertake ecological response modelling	

7.1.2.3 THE CRITERIA

A number of criteria were identified to enable the measurement of the performance of options. The criteria for this assessment were; cost of implementation, level of risk mitigated, efficacy, feasibility to implement, and benefits to regional community. These are defined as follows:

- **Cost of implementation:** the capital cost of establishment of required infrastructure together with ongoing maintenance costs over an economic life (20 years).
- **Level of risk mitigated:** the level of risk (high, medium or low) that the option or action undertaken is expected to mitigate. For example, the level of risk to existing tourism sites from sea level rise is expected to be relatively high. Therefore, undertaking work to promote different types of tourism at existing sites or to establish new sites would be expected to mitigate an impact with a high level of risk.
- **Efficacy:** the effectiveness of this option to address the potential impacts of climate change.
- **Feasibility to implement:** considers how feasible it is to implement the option. For example, is there sufficient knowledge about how to replicate important sites at another location.
- **Benefits to regional community:** the direct and flow-on benefits of implementing an option to the regional community, where the region extends to Darwin and the economy of the Northern Territory.

For this analysis the criteria are given equal weight or importance.

7.1.2.4 SCORING THE PERFORMANCE OF OPTIONS

Scoring the performance of options against the criteria for this assessment has required the use of qualitative information. Data on which to base accurate estimates of the performance of each option is not available at this time. As this study provides only an initial assessment, orders of magnitude have been adopted to measure the performance of options. Table 7-2 shows the qualitative measures and the scores awarded. Scores are best interpreted as the performance of each option, relative to the performance of other options rather than relative to their performance against other criteria. For example, the efficacy of an option is scored on the assumption that all options are feasible, not relative to the feasibility of implementation.

Table 7-2: Qualitative performance measures and scores awarded

CRITERION	QUALITATIVE PERFORMANCE MEASURES AND SCORES AWARDED				
Cost of implementation	Very high (4)	High (3)	Medium (2)	Low (1)	
Level of risk mitigated	High (1)	Medium (2)	Low (3)		
Efficacy	High (1)	Moderate (2)	Neutral (3)	Poor (4)	Ineffective (5)
Feasibility to implement	Yes (1)	Uncertain (2)	No (3)		
Benefits to regional community	Very high (1)	High (2)	Medium (3)	Low (4)	

7.1.2.5 THE TRADE-OFF MATRIX

The trade-off matrix is arguably the most useful product from a MCA. It shows the ranking of options against each criterion. The trade-off matrix shows how each option has performed in comparison to other proposed options. It is the trade-off matrix on which the final prioritisation of options is based.

7.1.2.6 PRIORITISATION OF OPTIONS

Options are prioritised based on their aggregate score. The trade-off matrix is converted into a ranking matrix. This ranking of the performance of each option demonstrates what options are considered as having a high priority and that further work should be undertaken to fully scope the option.

7.2 RESULTS OF ANALYSIS AND DISCUSSION

Table 7-3, Table 7-4 and Table 7-5 show the performance of each option against individual criteria, the trade-off matrix, and the ranking of options based on aggregate scores, respectively.

The final ranking of options (Table 7-5) demonstrates that the (equally) best performing options, given the criteria adopted for this assessment are:

- To promote new forms of tourism at existing sites;
- Maintain access to priority sites;
- Managed crocodile numbers and minimise contact; and
- Manage key ecological sites to build resilience.

The trade-off matrix (Table 7-4) shows that the major differences in the performance of these options was between the cost of implementation and benefits to regional economy.

Opening new sites to visitors and two options put forward to maintain access were all ranked highly, despite the relatively high cost of implementation. Interestingly, the options ranked highest are those which facilitate the continuation of tourism activities within the catchment (e.g. access, swimming, wildlife viewing) rather than options requiring major infrastructure to secure sites of high ecological and or cultural value. Assigning weights or an order of importance to criteria might well have resulted in a different ranking. Hydrological modelling together with ecological response modelling would assist in more accurately estimating the cost of implementation which could well result in a more robust and reliable ranking of possible options.

As this analysis has been undertaken to inform an initial assessment of adaptation options, the results suggest that more resources are required to determine a set of performance criteria against which options can be measured and with which stakeholders are comfortable. More importantly, to implement any of these options, further research, in particular development of a DEM, is required to identify specific sites at risk and to enable the relocation of infrastructure, including access roads, to be located in areas identified as secure from sea level rise, flooding and/or storm surge. In addition, more reliable rainfall data, maps showing where cultural and anthropological sites of significance are located together with an ecological response model would enable a more robust assessment. Prioritisation of funding for further research could be undertaken in much the same approach as has been adopted for this assessment (refer Table 7-6) with each research project measured against the likely cost, the usefulness of research to inform decision-makers about specific sites at risk from climate change impacts, as well as against the feasibility of the research itself.

Table 7-3: Performance of option against criteria

OPTIONS	CRITERIA				
	COST OF IMPLEMENTATION VH/H/M/L	LEVEL OF RISK MITIGATED H/M/L	EFFICACY H/M/N/P/I	FEASIBILITY TO IMPLEMENT Y/N/U	BENEFITS TO REGIONAL COMMUNITY VH/H/M/L
Tourism					
Promote new tourism at existing sites	Medium	High	High	Yes	High
Open new sites	High	High	High	Yes	High
Replicate sites and/or create 'Living Museum'	Very high	Low	Ineffective	Uncertain	Low
Maintain access to priority sites	High	High	High	Yes	Very high
Maintain infrastructure at priority sites	High	Medium	High	Yes	Medium
Manage crocodile numbers and minimise human contact	Medium	High	High	Yes	High
Maintain World Heritage listing	Low	Medium	Neutral	Yes	High
Mining					
Rehabilitate past mining facilities	High	low	Poor	Uncertain	Low
Upgrade infrastructure for proposed mines	Very high	low	Neutral	Uncertain	High
Health and Safety					
Prevent introduction of tropical diseases	High	Low	Neutral	No	Medium
Develop incidence response plan	Low	Medium	Moderate	Yes	Medium
Upgrade safety communication	Low	Medium	Moderate	Yes	Medium
Ecology					
Educate visitors and residents and businesses	Medium	Medium	Moderate	Yes	Medium
Manage extractive uses for the Park	Low	Medium	Poor	Yes	Medium
Manage key ecological sites to build resilience	High	High	High	Yes	Very High
Structural protection of priority sites	Very high	High	Moderate	Uncertain	High
Transport and Communication					
Develop alternative forms of transport into and within Park	High	High	High	Uncertain	Medium
Construct all weather road access	Very high	Medium	High	Yes	Very high

Table 7-4: Non-measurable scores

OPTIONS	CRITERIA					AGGREGATE SCORE
	COST OF IMPLE-MENTATION VH/H/M/L 4,3,2,1	LEVEL OF RISK MITI-GATED H/M/L 1,2,3	EFFICACY H/M/N/P/I 1,2,3,4,5	FEASIBILITY TO IMPLEMENT Y/N/U 1,3,2	BENEFITS TO REGIONAL COMMUNITY VH/H/M/L 1,2,3,4	
Tourism						
Promote new tourism at existing sites	2	1	1	1	2	**7**
Open new sites	2	1	1	1	2	**8**
Replicate sites and/or create 'Living Museum'	4	3	5	2	4	**18**
Maintain access to priority sites	3	1	1	1	1	**7**
Maintain infrastructure at priority sites	3	2	1	1	3	**10**
Manage crocodile numbers and minimise human contact	2	1	1	1	2	**7**
Maintain World Heritage listing	1	2	3	1	2	**9**
Mining						
Rehabilitate past mining facilities	3	3	4	2	4	**16**
Upgrade infrastructure for proposed mines	4	3	3	2	2	**14**
Health and Safety						
Prevent introduction of tropical diseases	3	3	3	3	3	**15**
Develop incidence response plan	1	2	2	1	3	**9**
Upgrade safety communication	1	2	2	1	3	**9**
Ecology						
Educate visitors and residents and businesses	2	2	2	1	3	**10**
Manage extractive uses for the Park	1	2	4	1	3	**11**
Manage key ecological sites to build resilience	3	1	1	1	1	**7**
Structural protection of priority sites	4	1	2	2	2	**11**
Transport and Communication						
Develop alternative forms of transport into and within Park	3	1	1	2	3	**10**
Construct all weather road access	4	2	1	1	1	**9**

Table 7-5: Prioritisation of options

OPTIONS	AGGREGATE SCORE	RANK
Tourism		
Promote new tourism at existing sites	7	**1**
Open new sites	8	**2**
Replicate sites and/or create 'Living Museum'	18	**9**
Maintain access to priority sites	7	**1**
Maintain infrastructure at priority sites	10	**4**
Manage crocodile numbers and minimise human contact	7	**1**
Maintain World Heritage listing	9	**3**
Mining		
Rehabilitate past mining facilities	16	**8**
Upgrade infrastructure for proposed mines	14	**6**
Health and Safety		
Prevent introduction of tropical diseases	15	**7**
Develop incidence response plan	9	**3**
Upgrade safety communication	9	**3**
Ecology		
Educate visitors and residents and businesses	10	**4**
Manage extractive uses for the Park	11	**5**
Manage key ecological sites to build resilience	7	**1**
Structural protection of priority sites	11	**5**
Transport and Communication		
Develop alternative forms of transport into and within Park	10	**4**
Construct all weather road access	9	**3**

Table 7-6: Research options

RESEARCH OPTIONS	CRITERIA		
	COST	FEASIBILITY	USEFULNESS
Development of DEM	Very High	High	Extremely
Map of critical habitat areas	Medium	High	Highly
Map of important cultural sites	High	High	Moderately
Upgrade Bureau of Meteorology data	Very High	Moderate	Highly
Undertake hydraulic modelling	High	High	Moderately
Undertake ecological response modelling	Very High	Moderate	Highly

8 Conclusions

8.1 OUTCOMES AND OUTPUTS OF THE STUDY

As outlined in Section 1, the overall aim of this study was to model river system hydrodynamics to assess the risk of saltwater intrusion and extreme rainfall events on low-lying coastal wetlands of the SAR catchment, and to discuss the implications of government planning, management and policy responses.

In meeting the above aim, the study has:

- provided a multi-disciplinary methodology that can be used to assess like environments in the context of future climate change impacts such as sea level rise; and
- provided a desktop assessment of potential climate change impacts on the values of the SAR Catchment that will be of use to Parks Australia and other users and stakeholders in future management of the KNP.

The outcomes of the study were achieved through a staged process involving:

- identification of the key physical processes and ecological, cultural and socio-economic values of the SAR catchment;
- development and modelling of river system hydrodynamics with associated catchment (rainfall) and coastal (storm surge) inputs from additional modelling for existing and projected climate change under 2030 and 2070 scenarios;
- assessment of the potential impacts of climate change on the key physical processes and ecological, cultural and socio-economic values;
- use of a risk assessment process to assess the risks of projected climate change for 2030 and 2070 scenarios;
- development and initial evaluation of adaptation options to treat the risks; and
- assessment of the adaptation options including the relative costs of implementing such measures against a 'do nothing' option.

The results and key findings of these investigations and activities (i.e. the outputs of the study) are provided in each of the previous chapters of the report. These include:

- revised risk register which outlines key risks to the SAR catchment under the provided climate change scenarios;
- consolidated list of adaptation option which aim to treat the risks;
- potential qualitative indicators that can be used to determine when adaptation options may be implemented;
- an initial assessment of the above indicators in terms of the constraints/barriers to implementation and the possible organisations involved in implementation; and
- a preliminary economic assessment of adaptation options in the form of a multiple criteria analysis to determine relative costs and expected benefits of implementing each of the options.

The section below outlines the likely future implications for planning, management and policy for the Park based on the findings of the various elements of the study.

8.2 IMPLICATIONS FOR PLANNING, MANAGEMENT AND POLICY RESPONSES

Kakadu's regulatory and policy environment is well developed and is perceived to be effectively managing the current challenges facing the Park, including climate change. The key management document for Kakadu, the KNP MP, acknowledges the potential impacts climate change may have on the significant values of the Park, and outlines that further information is needed in a number of areas to be able to effectively undertake rehabilitation and protection measures.

Based on the key findings of this study, the following issues and opportunities have been identified in the context of future planning, management and policy responses.

8.2.1 KEY INFORMATION GAPS

Timely adaptation to climate change will be dependant on the ability to identify areas that may be significantly impacted through sea level rise, storm surge from more frequent and intense cyclones and changes to rainfall and being able to confidently predict the likelihood and severity of such changes. Based on the key findings of the study, in order for this to occur, some key information gaps will need to be addressed.

8.2.1.1 DIGITAL ELEVATION MODEL

The most fundamental information gap identified as part of the current study is a suitable Digital Elevation Model (DEM) for the area. Without this tool it is virtually impossible for Park managers to undertake a detailed assessment of the most important Park assets (values), determine which may be at the highest risk of climate change and which may need to be protected or conserved with any degree of certainty.

While new activities within the Park are required to satisfy the assessment processes under the impact guidelines of the KNP MP, these assessment processes do not currently require assessment of the impacts of projected sea level rise, storm surge and flooding on the proposal, e.g. whether it is located appropriately, whether the proposal is flexible/adaptable to a future where potential climate change impacts are realised.

Other mechanisms such as the *NT Planning Scheme* that provide prohibitions related to development within defined flood areas and storm surge areas do not apply within Kakadu. However, once again, even if these immunity levels were applied in Kakadu, no DEM is available on which to base inundation predictions. It is also worth noting that the assessment processes under the KNP MP apply to activities and not to decisions, which may also have an impact on the way in which Park Management is prepared for potential climate change impacts.

With the *Integrated Natural Resource Management Plan for the Northern Territory* (NTG, LCNT and NHT 2005) highlighting the importance of factoring siting and design into infrastructure that may be potentially impacted by *'sea level rise, increases in the intensity of cyclones and storm surge'*, this is something that will need more focus in planning, but will also require the fundamental underlying data required to do so.

8.2.1.2 SEDIMENT DYNAMICS

As well as a high resolution DEM, it is necessary to be able to model sediment dynamics. This includes regional sediment distribution through marine and fluvial processes as well as the local processes of flocculation and levee and dendritic channel formation. The quantification of these processes would require data providing both the expected regional sources of sediments (marine and fluvial) and rates of delivery. Also, an understanding of the local processes of levee building and dendritic channel formation are essential for controlling the rate of fresh and saltwater delivery from and to the floodplain, as is an understanding of local dynamics of flocculation, scour and sedimentation which also influence these processes.

A morphological model, based on the underlying hydrodynamics and definition of the sediment characteristics was made available for this study. When a suitable DEM is available and sufficient information on sediments characteristics and dynamics in the estuary and on the floodplain are also available then this model could be used to assess climate change impacts on the estuary.

8.2.2 FUTURE RISK ASSESSMENT

The risk assessment process presented in Section 5 followed the Australian Standard for Risk Management (AS/NZS 4630: 2004) and assessed the consequence and likelihood of risks determined from the impact assessment through a consideration of sea level rise, storm surge related to more intense and frequent cyclones and rainfall changes. At 2030, over 50% of risks were considered low or medium, while at 2070 over 50% of risks were considered high or extreme, with extreme risk levels determined for two ecological, two cultural and one tourism risk. This possibly indicates that the control measures and mechanisms protecting or managing socio-economic values inherently have built into them review processes or maintenance requirements that allow them to ‘keep pace’ with the potential progression of climate change impacts. On the other hand, ecological and cultural values have historically changed and evolved with climate, however as they are predominantly based on aspects, or are reliant on the natural environment, if the natural environment cannot evolve to keep pace with climate change impacts, in some cases, the risk of impact to these values becomes high or extreme.

The risk assessment and associated risk register developed as part of the study provides a ‘starting point’ for assessing future risk. Management tools such as the risk acceptability continuum (refer Figure 5-4) together with the identification of environmental values, provides a framework to define some of the key indicators for assessing future climate change. In this context a similar risk assessment process (using the risk register presented in Table 5-7 as the baseline) can be re-visited at any time by Park staff as part of future management plan reviews.

The selection of the environmental value species and habitats was done in part on their susceptibility to future climate change and monitoring of these ‘biotic’ indicators over time may be the best means of identifying when climate change risks are approaching a level of unacceptability (e.g. the red zone of the continuum within Figure 5-4).

In this context, an important focus for future work will be to try to set some quantitative triggers for management intervention based on key indicators for these species and habitats (e.g. such as observed reductions in wildlife populations, reduced usage of the site in terms of abundance or breeding, observed reduction in habitat extent and similar limits of acceptable change). While these quantitative limits are inherently difficult in an ecosystem like the SAR that is so naturally variable, this approach is perhaps the best means of triggering more active responses to climate change (e.g. the consideration of adaptation options such as the construction of levees, habitat relocation, or access closures) before an unacceptable impact has occurred.

Based on the above, it would seem appropriate in the short term that Governments continue to invest in research and activities that prepare decision-makers for the harder decisions that inevitably lie ahead. This could include for example, further data collection (the DEM in particular), refinement of the numerical models (see below), and further assessment of potential adaptation options identified as part of the adaptation workshop including for example pilot projects in terms of engineering solutions (such as bunds and barrages) and possible habitat manipulation projects (enhancement, restoration, species relocation and similar).

8.2.3 FURTHER REFINEMENT AND USE OF THE NUMERICAL MODELS

A hydrodynamic numerical model of the tidal channel and floodplain was developed as part of the current study, with inputs from coastal and catchment models, for existing and future climate change scenarios at 2030 and 2070. The hydrodynamic modelling undertaken showed that under the 2030 and 2070 scenarios, more frequent and longer periods of saltwater inundation of freshwater floodplains could be expected when compared with the existing scenario. The development of these models used the best data available to the study team. However, some key datasets were not available for the study. These included:

- the digital elevation model (refer Section 8.2.1.2) which was not of sufficient resolution/accuracy to be able to provide accurate and reliable results in the modelling; and
- sediment characteristics for the floodplain and the estuary (refer Section 8.2.1.3) which are essential for geomorphological modelling. This also includes delivery of sediments (fluvial and marine) and the tidal zone dynamics (flocculation and levee building/scouring).

These significant data gaps meant that only qualitative assessments could be made of the impacts to the values of the SAR catchment. Similar issues were experienced with the catchment model due to a lack of stream gauging within the catchment.

More generally the lack of an established survey datum in the region restricts the collection of reliable elevation data for modelling and other purposes.

Acquisition of a quality DEM and sediment characteristic data for the floodplain and estuary may allow for future use of the existing tidal and floodplain model created as part of the study, including in a predictive capacity. In particular, the model has the ability to take the subtle detail on an essentially flat floodplain and simulate water flow into and out of the billabongs, paleochannels and other water retaining features. In this case the impacts of sea level rise could be modelled in a more accurate way. In addition, the model is capable of simulating the sedimentation processes associated with increased channel flow, increased sediment inflow from the catchment and flocculation. These processes are essential for levee building and with appropriate data the ability of the system to respond to sea level rise could be modelled.

The model would also be applicable for use in sensitivity analyses including the likelihood of cut road access, the incidence of flooding in developed/important areas and similar uses which would be of benefit in the investigation and implementation of future adaptation actions.

8.2.4 FURTHER ASSESSMENT OF POTENTIAL ADAPTATION OPTIONS

Adaptation options to treat the risks of climate change were developed and assessed for effectiveness and efficiency as part of the current study. The initial assessment undertaken by the study team provided an overview of the assessment for each of the options and also provided an opportunity to examine the potential timeframe for implementation of adaptation options using a 'continuum of acceptability.' The final component of the assessment was the multiple criteria analysis which provided an assessment approach that was sufficiently comprehensive to facilitate the incorporation of information from multiple disciplines, sufficiently transparent to demonstrate the magnitude of the trade-offs and sufficiently flexible to enable the inclusion of both quantitative (where available) and qualitative information.

Engagement with Bininj and key stakeholders through the process ensured that all significant values, impacts and risks were canvassed and verified through consultative processes, and that proposed adaptation options received preliminary vetting and were generally considered acceptable for implementation in Kakadu. Consultation also provided a forum for provision of study results back to Bininj and stakeholders.

In the spirit of joint management, Policy 5.6.1 of the KNP MP states that:

> *'…if parts of the landscape are changing in ways that are of concern, the Director [of National Parks] and Binninj, in consultation with relevant stakeholders, will jointly decide on further monitoring requirements, and whether protective, rehabilitation or adaptation measures are feasible.'*

It also states that appropriate actions to address potential climate change impacts will only be implemented if they are cost-effective. While no absolute values were available to undertake a cost-benefit analysis for this study, the multiple criteria analysis in Section 7 (and the initial assessment of adaptation options conducted by Bininj and key stakeholders) provide some indication of the options that may be most easily and cost-effectively implemented.

In planning for or undertaking any climate change adaptation options in the future, the 'low-hanging fruit' and 'no regrets' options identified as part of this study will likely require limited additional resources in terms of funding, time and staffing requirements. However, those options that require significant resources for implementation may put additional strain on the system. Where easily implemented, options can be put in place in the near future, and data gathered to provide baseline information and the basis for ongoing management. This may reduce the longer-term costs of implementing additional adaptation options or, following a review of the risk levels, may postpone the required implementation of an option.

One potential problem that could be faced by Park managers in implementation of adaptation options, particularly those options that require consistency with management approach from outside the Park, is that Kakadu is federally-funded and jointly managed, while located within the Northern Territory. Effectively this unique management arrangement means that Kakadu is often viewed as an 'island' (Commonwealth of Australia 2005). While Kakadu National Park has developed a draft Climate Change Strategy, implementation of actions may require coordination across jurisdictions. The Northern Territory Government is developing a Climate Change Policy which is likely to propose the development of a Territory-wide Adaptation Action Plan.

It is important to note that the process used in this study is not designed to provide an absolute outcome, or to provide the final set of adaptation options for implementation to address the risks. Risk assessment and adaptation option assessment is an iterative process. The list of adaptation options presented is not exhaustive, or static. Using the assessment processes identified and reviewing the information provided in this document on a regular basis, will assist managers to decide which options may be most appropriate for implementation at any given time.

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Appendix A: Traditional Owners and Stakeholders Approved for Consultation

STAKEHOLDER	KEY CONTACT
Key Stakeholders	
Park Management team	Park Manager Sarah Kerin (08) 89381100 Sarah.Kerin@environment.gov.au
Board of Management	BoM Exec Officer Gabrielle O'Loughlin (08) 8938 1109 Gabrielle.O'Loughlin@environment.gov.au
Traditional owners of the South Alligator region	Northern Land Council Kakadu Park Officer Sean Moran (08) 8938 1138
Northern Land Council	Northern Land Council Kakadu Anthropologist Eva Purvis (08) 8920 5151 Eva.purvis@nlc.org.au
Kakadu Research Advisory Committee Note: Ensure AIMS, CDU & UWA reps	Bob Wasson Bob.wasson@cdu.edu.au (08) 8946 7444
Aboriginal Areas Protection Authority	(08) 8981 4700
Alligator Rivers Region Advisory Committee	ARRAC Secretariat Phone: (08) 8920 1124
Kakadu Tourism Consultative Committee	Chair KTCC Rick Murray Telephone: 08 8948 1941 Kakadu National Park Tourism and Visitor Services Manager Imelda Dover (08) 8939 1107
Tourism NT	Darwin office: (08) 8999 3900 Natasha Smith
Department of Primary Industries, Fisheries and Mines – NT Fisheries	General Enquiries fisheries@nt.gov.au 08 8999 2144 A/H 0438 159244 Phil Hall (Ph: 08 8999 2372, phil.hall@nt.gov.au,) Rec fishing& fishing tour operators (joint mgt tour op.s-DSEWPaC in Kak)
AFANT – Amateur Fishermens' Association of the Northern Territory	(08) 8945 6455 research@afant.com.au Chris Makepeace chris@afant.com.au (Mob: 0415 471 600)
Energy Resources of Australia Ranger Uranium Mine – Technical Committee	(08) 8938 1211 http://www.energyres.com.au/

STAKEHOLDER	KEY CONTACT
West Arnhem Shire Council	CEO – Mark Griffioen (08) 8979 9444 mark.griffioen@westarnhem.nt.gov.au http://www.westarnhem.nt.gov.au/
Bureau of Meteorology	Regional Office Tel: (08) 8920 3800
Suggested Stakeholder	
Environmental Research Institute of the Supervising Scientist	Jabiru office: (08) 8979 9700 Darwin office: (08) 8920 1100
NRETA (Natural Resources, Environment and The Arts)	(Steering Committee contact) CC Policy – Paul Purdon (08 8924 4070; paul.purdon@nt.gov.au)
Power and Water Authority	www.powerwater.com.au
Emergency Services	Peter Davies (peter.davies@nt.gov.au) (08) 8922 2629

Current at March 2009.

Appendix B: Workshop Participants

Note: Representatives from all stakeholder groups identified in Appendix A were invited to the workshop. Appendix B outlines those stakeholders that attended the workshop.

Registration Sheet

NCRA Kakadu Case Study – Risk Assessment and Adaptation Options Workshop (21–22 April 2009)

NAME	ORGANISATION (IF RELEVANT)	EMAIL	PHONE	DAY 1	DAY 2
Paul Jonauskas	NRETAS	paul.jonauskas@nt.gov.au; toomuddy@bigpond.net.au	8999 4569	x	x
David Dettrick	EWL Sciences	david.dettrick@ewlsciences.com.au	0417 561 074	x	x
Basil Bulkua	ERA	Basil.Bulkua@era.riotinto.com	0437 321 705	x	
David Jones	ERISS/SSO	david.jones@environment.gov.au	8920 1104	x	
Joseph Nagawali	KNP			x	
Shannon Murray	KNP	shannon.murray@environment.gov.au	8938 1170	x	
Patrick Shaugnessy	KNP	patrick.shaughnessy@environment.gov.au	8979 2291	x	x
Sarah Kerin	KNP	sarah.kerin@environment.gov.au	8938 1199	x	
Ian Irvine	KNP	ian.irvine@environment.gov.au	8938 1114	x	x
Mick Gorst	KNP	mick.gorst@environment.gov.au	8979 0192	x	
Trish Flores	KNP	trish.flores@environment.gov.au	8938 1155	x	
Steve Winderlich	KNP	Steve.winderlich@environment.gov.au	8938 1172	x	x
Natasha Smith	Tourism NT	Natasha.smith@nt.gov.au	8999 5243	x	x
Dot Corrie	KNP	Dot.corrie@environment.gov.au	8938 1100	x	
Michelle Hatt	KNP	Michelle.hatt@environment.gov.au	8938 1162	x	
Hank Schinkel	KNP	Hank.Schinkel@environment.gov.au	8931 1105	x	
Katherine Wilson	KNP (Jim Jim)	Katherine.wilson@environment.gov.au	8979 2038	x	x
Joe Markham	KNP (Mary River)	Joe. markham@environment.gov.au	8975 4578	x	
Jeff Lee	KNP (Jim Jim)	Jeff.lee@environment.gov.au	8979 2038	x	
Peter Butler	KNP (Jim Jim)	Peter.butler@environment.gov.au	8979 2038	x	x
Dave Lindner				x	x
Oliver Scheibe	KNP	Ollie.scheibe@environment.gov.au	8938 1180	x	x
Fred Baird	KNP	Frederick.baird@environment.gov.au	8979 2038	x	
Jonathon Nadji	KNP		8938 1165	x	
Garry Lindner	KNP		8938 1165	x	
Bessie Coleman	KNP (Mary River)		8975 4578	x	
Beryl Smith	KNP (Mary River)		8975 4578	x	
Billy Fordham	KNP (Mary River)		8975 4578	x	
Sean Moran	NLC	Sean.moran@environment.gov.au		x	
Steve Johns	KNP (East Alligator)	Steven.johns@environment.gov.au	8979 2291	x	
Ralph F. Blyth	West Arnhem Shire	president@westarnhem.nt.gov.au	8979 9444 0408 898 609		x
Mary Blyth	KNP	Mary.blyth@environment.gov.au	8938 1100	x	x

NAME	ORGANISATION (IF RELEVANT)	EMAIL	PHONE	DAY 1	DAY 2
Violet Lawson					x
Zig Madycki	KNP	Zig.madycki@environment.gov.au	8975 4578	x	x
Sally-Anne Atkins	KNP			x	x
Anne O'Dea	KNP			x	
Meredith Billington	KNP	Meredith.billington@environment.gov.au		x	

Appendix C: Consultation Summary

Consultation Summary: National Coastal Vulnerability Assessment: Kakadu National Park

Prepared by Michelle McKemey (May 2009); Reviewed by Megan Ward and Lyn Léger (June 2009)

Aims and Objectives

As a component of the Kakadu Climate Change NCVA project, consultation with traditional owners and Aboriginal people associated with Kakadu National Park (South Alligator River catchment) was undertaken. The purpose of the consultation was to fulfil the objectives of the NCVA Kakadu Case Study consultation strategy, outlined as follows:

- To meet the requirements of the Department of Climate Change and Energy Efficiency as set out in the Request for Tender;
- To engage key stakeholders in order to gather information;
- To empower key stakeholders to provide input into the study; and
- To provide a forum to present study results to key stakeholders.

Additionally, the consultation fulfilled the conditions of the research permit granted by Kakadu National Park, for which Traditional Owner consultation was advised by the Northern Land Council.

The Kakadu Board of Management requested that the project was aligned with other climate change projects in the region, in order for Parks Australia North to build on regional knowledge and to avoid duplication in Traditional Owner consultation. For the same reasons, it was also requested that Park staff were involved with the consultation process and given full access to the information obtained.

Process

The Northern Land Council provided Land Interest Reference information to Kakadu National Park. Working through Kakadu National Park and Northern Land Council staff, members of the project team made contact with traditional owners and relevant Aboriginal people to discuss the project.

Additionally, several discussions were held with the Anthropologist for the Kakadu region (Northern Land Council), the Kakadu Park Officer (Northern Land Council) and an officer of the Cultural Heritage section of Kakadu National Park. This consultation primarily sought to contact senior traditional owners living in Kakadu, as well as to inform traditional owners not living in Kakadu that the project was underway.

Consultation trips were undertaken in February 2009 and April 2009 in order to seek Traditional Owner participation. During these trips, relevant Aboriginal people were informed of the project, and information was collected on their views of values of Kakadu, and risks and potential options to manage the impacts of climate change in Kakadu.

Consultation was undertaken in the form of meetings at ranger stations; visits to outstations, homes, businesses and Aboriginal associations; workshops at Park head quarters; telephone calls; and simple information sheets. At each consultation event, notes were taken and maps were used to illustrate spatial issues. Due to confidentiality, specific notes cannot be presented within this report. However, a summary of the results from these consultations have been provided to Parks Australia North.

A total of 31 relevant Aboriginal people were consulted during the project, and attempts were made to consult with at least 9 others who were unavailable to participate. Sitting fees or reimbursement of fuel costs were paid to those traditional owners who participated in the workshop or travelled to ranger stations to participate in meetings.

Conclusion

Substantial effort was made by the project team to consult with traditional owners as listed on the Land Interest Reference. During the consultation trips and follow-up correspondence, many of these traditional owners were able to participate in the project and contributed valuable input. It is the view of the research team that all efforts were made to fulfil the requirements of the research permit.

Appendix D: Habitat Classification System

In order to conduct the ecological assessment, an appropriate habitat classification system for the study area was established. Firstly, the following sections of the catchment were identified based on geomorphology (after Woodroffe *et al.* 1985):

- *Coastal Plain:* The seaward section formed largely by deposition of marine sediments.
- *Deltaic Estuarine Plain:* The tidal section of the river and the adjacent areas.
- *Alluvial Plain:* The seasonally inundated flood basin above the tidal reaches.

Secondly, the presence or absence of major habitat types within each of the above sections was determined, including marine waters, mudflats, mangroves, saltmarsh, channel, billabongs, seasonally inundated floodplain, fringing Melaleuca, lowland (monsoon) rainforest and woodlands. All but two of these habitat types (marine waters, channel) are characterised by a distinct vegetation community that is composed of plant species suited to the specific attributes of each habitat. In particular, the degree of tidal and/or freshwater inundation as determined by their location and elevation within the landscape.

Within each of the habitat types, ecological values were identified including species and communities of conservation significance[39], keystone species, iconic species and culturally significant species. Additionally, the known presence of exotic flora and fauna was noted for habitat types.

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39 Listed as nationally rare, vulnerable or endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and/or internationally listed on the IUCN 2008 Red List.

Appendix E: Habitat Types and Their Features

Marine Aquatic

Although not considered prime habitat for marine turtles, species of conservation significance that occur in coastal waters of the study site include the nationally endangered loggerhead and olive ridley turtles and the nationally vulnerable flatback and green turtles (Vanderlely 1995, Chatto and Baker 2008). These species are internationally listed as endangered, vulnerable, endangered and data deficient, respectively.

Mudflats

Intertidal mudflats are extensive along the shoreline. Broad, low-lying hypersaline mudflats that are largely unvegetated also adjoin the river and creeks on the landward side of mangroves. Intertidal mudflats support large aggregations of shorebirds, including species such as whimbrel, eastern curlew and black-tailed godwit that are recognised in bilateral agreements for shorebird conservation between Australia and Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA).

Mangroves

Mangroves have extensively colonised the coastal shoreline as well as tidal reaches of the main channel and its tributaries, becoming increasingly fragmented inland and along smaller creeks (Finlayson and Woodroffe 1996). Mangrove communities are relatively floristically diverse, with thirty-eight mangrove species identified within the Alligator Rivers Region (Wightman 1989). Many of these species are widespread in coastal Australia and throughout the Indo-Malesian biogeographic region (Duke 1992). In the coastal region, species composition is typically grey mangrove *Avicennia marina* on the landward side, a central band of spider mangrove *Rhizophora stylosa* and a seaward distribution of white mangrove *Sonneratia alba* (Davie 1985), while *Sonneratia lanceolata* occurs upstream (Finlayson et al. 1988).

Mangroves potentially provide habitat for the nationally vulnerable species water rat (*Xeromys myoides*). A number of other fauna species are known to utilise mangrove habitats, including saltwater crocodiles, snakes, lizards, geckos, turtles and bats, as well as feral buffalo, pigs and cattle (Hegerl et al 1979, Milward 1982).

Cultural importance of mangroves to indigenous people includes various uses of flora and fauna for food, medicine and the construction of weapons and artworks. Food sources include fish, stingrays, mammals, reptiles, invertebrates and honey (Puruntatameri et al 2001).

Mangrove communities have an important function in coastal stabilisation through protection against coastal erosion, and create a buffer against extreme weather events. Further, mangroves have a role in sediment trapping and consequently contribute to the quality of coastal waters. High productivity associated with mangrove communities supports complex ecosystems, including species that are important for recreation and commercial fisheries such as prawns and barramundi.

Saltmarsh

Although salt-flats lacking vegetation are more common (Macnae 1966), saltmarsh communities may inhabit salt-flats in the coastal zone, and also fringe the river in parts of the lower estuarine section. Saltmarsh communities are floristically poor, with succulent shrub species present including *Halosarcia indica, Suaeda arbusculoides, Tecticornia australasica* and *Sesuvium portulacastrum*, and grasses including *Cynodon dactylon* and *Sporobolus virginicus* (Russell-Smith 1995). These species are cosmopolitan in distribution, generally occurring throughout much of coastal Australia.

Channel

The nationally critically endangered speartooth shark and endangered northern river shark have previously been recorded in the lower reaches of the South Alligator River (Stevens *et al.* 2005). The river channel also provides habitat for iconic and culturally significant species such as Saltwater Crocodiles in tidal and freshwater sections, and freshwater crocodiles in freshwater sections. Crocodiles, sharks, stingrays, flounder and mudcrabs are important bush tucker species that inhabit the saline reaches of the channel.

Billabongs

Permanent freshwater bodies exist in the form of billabongs (lagoons) and small lakes (Finlayson et al. 1988). Mixed community herblands comprised of submerged, floating and emergent plant species are associated with permanent billabongs. These communities are often dominated by waterlilies such as white snowflake lily *Nymphoides indica* and the bush tucker species red lily *Nelumbo nucifera*, with other macrophyte species including *Limnophila australis, Triglochin dubium* and *Caldesia oligococca* (Finlayson 2005). Mat-forming grasses may include *Leersia hexandra* and *Hymenachne acutigluma*. Melaleuca swamps and other trees may occur on the margins of billabongs (see below).

Billabongs provide dry season refuges for many of the aquatic fauna species that inhabit the floodplains (refer below). Diversity of freshwater fish is high, and large numbers of water birds use the billabongs. Billabongs also support iconic fauna species such as Freshwater Crocodile, and species that are an indigenous food source such as file snake and freshwater turtles. Billabongs along the South Alligator River represent a significant refuge for pig-nosed turtle (Press et al 1995), an internationally vulnerable and important bush tucker species.

Seasonally Inundated Floodplains

Vast tracts of freshwater wetlands comprise the seasonally inundated alluvial floodplains. While vegetation is sparsely distributed during the dry season, floodplain wetlands are covered with 1-2 m of water and a multitude of plants during the wet season (Finlayson and Woodroffe 1996). The floodplain wetlands are primarily sedge- and/or grass-dominated meadows that form complex spatial mosaics. Flora species comprising the floodplain wetlands are predominantly cosmopolitan in distribution (Taylor and Dunlop 1985), with characteristic species including wild rice *Oryza* spp., spike-rush *Eleocharis* spp., *Hymenachne acutigluma* and water couch *Pseudoraphis spinescens* (Russell-Smith 1995; Finlayson 2005). Commonly encountered waterlilies include blue waterlily *Nymphaea violaceae*, yellow snowflake lily *Nymphoides hydrocharoides* and white snowflake lily *Nymphoides indica*.

Large areas of Melaleuca swamp forest occur in the floodplains along billabong and stream edges, and are inundated by up to one meter of water during the wet season (Finlayson 2005). Dominant species include broad-leafed paperbark *Melaleuca viridiflora* and white paperbark *Melaleuca leucadendra*, with other tree species commonly encountered including freshwater mangrove *Barringtonia acutangula* and screw pine *Pandanus spiralis* (Finlayson 2005).

Keystone flora species of freshwater floodplains include Eleocharis sphacelata that is used by magpie geese for nesting, seeds of *Oryza meridionalis* and tubers of *Eleocharis dulcis* that are eaten by magpie geese, and Melaleuca trees due to their habitat provisioning values. Many traditional dietary staple plant species are associated with freshwater habitats. For example, Eleocharis spp. provide edible yams, and waterlilies are of particular importance to traditional regional economy due to their starchy seed heads (Lucas and Russell-Smith 1993).

Freshwater floodplains support high numbers of fauna species, including freshwater and saltwater crocodiles (Webb *et al.* 1983), file snake (Shine 1986), freshwater turtles, freshwater fish (Bishop et al. 1981), freshwater mussels (Humphrey and Simpson 1985) and a diversity of water birds (Morton and Brennan 1986). Many of these species are an important indigenous food source.

The particular value of freshwater floodplains to waterbirds is well-recognised, with iconic species present including magpie goose *Anseranas semipalmata*, brolga *Grus rubicunda*, jabiru *Ephippiorhynchus asiaticus* and comb-crested jacana *Irediparra gallinacean*, and nationally endangered species such as yellow chat *Epthianura crocea*. Substantial numbers of waterbirds have been recorded (e.g. Morton et al 1989, Chatto 2006), with numerically dominant species including magpie geese *Anseranas semipalmata* and wandering whistling-duck *Dendrocygna arcuata*. Waterbird usage of floodplains fluctuates seasonally, with maximum numbers for most species occurs during dry season. In particular, floodplains of the South Alligator River are the major dry season refuge in the Northern Territory for magpie geese (Bayliss and Yeomans 1990).

The weed species *Mimosa pigra* and *Salvinia molesta* have become prominent features of some floodplains and are subject to ongoing management. Habitat modification by feral animals has previously been extensive, notably by water buffalo and pigs, but control programs for feral animals have been successful.

Lowland Rainforest

Along the margins of freshwater wetlands and mangrove communities, relatively restricted pockets of monsoon forest occur at scattered locations in coastal and seasonally dry floodplains where the soil moisture status is locally high (Bowman and Wightman 1985; Bowman and Dunlop 1986). A large proportion of the flora species comprising monsoon forests have extra-Australian distributions, while the remaining proportion of species is widespread across the north (Liddle *et al.* 1994). Commonly encountered species include styptic tree *Canarium australianum* and banyan tree *Ficus virens*. A range of reptile, amphibian, mammal and bird species are known to inhabit monsoon rainforest, although most species are not exclusively restricted to this habitat type.

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Appendix F: Values and Life Histories of Key Environmental Values

1 Aquatic macrophytes in freshwater billabongs and seasonally ponded floodplains

Permanent freshwater billabongs and seasonal floodplains are an iconic habitat type of Kakadu. Billabongs and seasonal floodplains support a variety of fauna species, particularly during the dry season when they provide refuge for many aquatic species. Numerous fauna species associated with billabongs and seasonal floodplains are notable for a variety of reasons including iconic, bushtucker and threatened species (e.g. crocodiles, file snakes, turtles). Billabongs such as Yellow Waters are also of value due to their tourism and recreational significance.

A number of flora species associated with billabongs and freshwater floodplains are important due to their habitat and bushtucker values. These include waterlilies inhabiting billabongs and seasonal floodplains, trees (e.g. *Pandanus* spp., *Melaleuca* spp.) inhabiting billabong margins and seasonal floodplains, and the sedges (e.g. *Eleocharis* spp.) and grasses (e.g. *Oryza* spp.) of the seasonal floodplains. These species have varying habitat requirements, but in general are dependent on the presence of freshwater at varying depths.

Billabongs and freshwater floodplains are subject to dramatic variation due to the highly seasonal nature of the climate. While billabongs represent a permanent watersource, seasonal floodplains are covered with 1–2 m of water during the wet season and are dry for the remainder of the year (Cowie *et al.* 2000). The rate, timing, depth and extent of flooding exert a major control over plant growth and community composition. In billabongs, there is a generalized uniformity of physico-chemical conditions during periods of stream flow and a progressive increase in solute levels during the dry season. Runoff after early wet season storms flushes billabongs.

Herbivory may also contribute to the control of extent and abundance of flora species comprising billabong and seasonal floodplain habitats, particularly with respect to smaller herbaceous flora species.

Table 3-1: Key controls on freshwater billabongs and seasonally ponded floodplains

KEY CONTROLS	ATTRIBUTE				
	WATERLILIES	*ELEOCHARIS*	*MELALEUCA*	*PANDANUS*	*ORYZA*
Habitat	Billabongs; seasonally inundated floodplains	Seasonally inundated floodplains	Seasonally inundated floodplains and billabong margins	Billabong margins	Seasonally inundated floodplains
Hydrological	Habitat permanency and extent	Rate, timing and depth of flooding	Data deficient	Data deficient	Seasonal inundation
Climate	Flowering generally all year and autumn/winter fruiting (species dependent)	Summer growth	Winter/spring flowering	Winter flowering; winter/spring fruiting	Summer growth and seeding
Geomorphology	Organic freshwater fine-grained sediments	Organic freshwater fine-grained sediments	Organic freshwater fine-grained sediments	Organic freshwater fine-grained sediments	Organic freshwater fine-grained sediments
Physio-chemical	Salt intolerant; nutrient availability	Some species tolerate low salinity	Salt intolerant	Data deficient	Some species tolerate low salinity
Biological interactions	Herbivory	Herbivory (especially by magpie geese)	Data deficient	Herbivory of fruit	Herbivory (especially by magpie geese)

2 Monsoon rainforest

Along the margins of freshwater wetlands and mangrove communities, relatively restricted pockets of monsoon rainforest occur at scattered locations in coastal and seasonally dry floodplains. Sacred sites for indigenous communities are found within monsoon rainforest. Many important bushtucker species inhabit monsoon rainforest, such as yam as well as a variety of fauna including reptiles, mammals and birds.

Monsoon rainforest occurs where the soil moisture status is locally high (Bowman and Wightman 1985; Bowman and Dunlop 1986). These sites are typically on deeply weathered lateritic soils or organic sediments. Many of the tree species comprising monsoon rainforest are deciduous, dropping their leaves during the dry season in order to conserve moisture.

3 Woodlands

Woodland vegetation communities occur at higher elevations and are consequently not seasonally inundated. Woodland habitat types are predominantly composed of Eucalypts, with a tall grassy understory. Sacred sites for indigenous communities often occur within woodlands (Chaloupka 1993).

4 Potadromous freshwater fish

At least 41 freshwater fish species are known to occur in the Alligator Rivers Region (excluding marine vagrants). Of these, 20% of species are catadromous (breeding in marine or estuarine environments – see barramundi below), whereas most of the remaining 80% do not have an obligate estuarine phase and are termed potadromous species. None of these species are endemic to the region or are considered threatened, although the ARR is considered to represent a core area for four of these species (Magela hardyhead, exquisite rainbowfish, Midgley grunter and sharp-nose grunter). All four of these species are primarily restricted to sandstone escarpments outside the influence of SLR (Bayliss *et al.* 1997).

Spawning and migrations are strongly linked to hydrological cycles. Many species spawn in offstream billabongs and floodplain habitats, typically during the early and pre-wet to take advantage of increased floodplain habitat and food resources upon hatching during the wet. Upstream migrations of some species can take place during the late wet, with fish moving from floodplain nurseries to dry season refugia.

5 Pig-nose turtles

Pig-nosed turtle (*Carettochelys insculpta*) is a notable species due to its conservation status. This species is listed internationally as a vulnerable species, and as a near threatened species under Northern Territory legislation (*Territory Parks and Wildlife Conservation Act 2000*). Additionally, adult pig-nosed turtles are an important indigenous food source (there are no records of eggs being harvested).

Pig-nosed turtles are a freshwater species, favouring still waters with an approximate depth of 2 m (Legler, 1980, 1982; Georges and Kennett, 1989). Billabongs along the South Alligator River are known to represent a significant refuge for this species (Press *et al.* 1995). Cover for pig-nosed turtles within billabongs is provided by characteristics such as fallen branches, exposed roots and undercut banks.

While males are almost entirely aquatic, females leave the water to nest on sandy banks and lay eggs during the dry season. Pig-nosed turtles produce larger and more eggs per clutch following 'big' wet seasons as compared to 'small' wet seasons (Doody *et al.* 2003). When the offspring is fully developed, they will hibernate inside the eggs until the wet season when eggs have been flooded with water, resulting in hatchlings emerging under optimal seasonal conditions. Hatchling sex ratios are dependent on the temperature at which eggs are incubated (Webb *et al.*, 1986, Georges 1992).

Pig-nosed turtles are omnivorous, with a diet including leaves, flowers, fruit, invertebrates and fish (Schodde *et al.* 1972). This diversity of food sources enables opportunism, allowing varying exploitation of resources dependent on availability. Threats to pig-nosed turtles include feral buffalo trampling of nests, eggs and riparian vegetation; and predators such as reptiles that feed on pig-nosed turtle eggs.

Table 3-2: Key controls on pig-nosed turtles

KEY CONTROLS	ATTRIBUTE		
	NESTING	FEEDING	ABUNDANCE
Habitat	Riverbanks	Billabongs	Billabongs
Hydrological	Clutch and egg size vary with intensity of wet season; offspring hibernate inside eggs until nest is flooded	Still water approximately 2m deep	Still water approximately 2m deep
Climate	Lay in dry season and hatch in wet season; hatchling sex ratio dependent on temperature	Data deficient	Data deficient
Geomorphology	Fine sand	Sand and gravel substratum covered with fine layer of silt	Sand and gravel substratum covered with fine layer of silt
Physio-chemical	Eggs require freshwater inundation, susceptible to salinity	Freshwater	Freshwater
Biological interactions	Predation by reptiles and amphibians	Omnivorous, feeding on leaves, flowers, fruit, invertebrates and fish	Data deficient

6 Freshwater crocodiles

The freshwater crocodile (*Crocodylus johnstoni*) is an important species for indigenous communities, providing bushtucker in the form of meat and eggs, and representing a totemic species. Freshwater crocodiles are of ecological value due to their control over community structure as a dominant predator. Freshwater crocodiles are protected as marine species under Commonwealth legislation, and are listed internationally as a least concern species.

Freshwater crocodiles inhabit various freshwater environments, including channel, billabong floodplain, and bank habitats. Freshwater crocodiles move late in the wet season to stay in close proximity to permanent water during the dry season. This species is generally not found near the coast where the salinity is higher and competition with the more dominant saltwater crocodile is greater.

Females dig holes in sand embankments as nests. Nesting occurs during the dry season, after the water levels fall and riverbanks are exposed. Early wet season flooding can be detrimental to nesting success as embryos will drown if eggs are inundated. The temperature at which eggs are incubated determines the sex-ratio of hatchlings (Whitehead *et al.* 1990).

While freshwater crocodiles are primarily adapted for a piscivorous diet, a large proportion of food is obtained from the terrestrial environment. Freshwater crocodiles eat less during the dry season, particularly when temperatures are low (Webb *et al.* 1982).

Table 3-3: Key controls on freshwater crocodiles

KEY CONTROLS	ATTRIBUTES				
	NESTING	FEEDING	ABUNDANCE	BASKING	MOVEMENTS
Habitat	River banks	Channel, billabongs, floodplains	Channel, billabongs, floodplains	Riverbanks	River channel
Hydrological	Flooding of nests catastrophic to success	Data deficient	Data deficient	Data deficient	Data deficient
Climate	Dry season nesting; temperature dependent sex ratio	Less feeding during dry season	Growth primarily occurs during the wet season (when food is abundant)	Data deficient	Seasonal movement to remain close to water
Geomorphology	Sandy substrates	Data deficient	Data deficient	Data deficient	Data deficient
Physio-chemical	Freshwater but tolerant of low salinity	Freshwater but tolerant of low salinity	Freshwater but tolerant of low salinity		Freshwater but tolerant of low salinity
Biological interactions	Predation on eggs and hatchlings primarily by reptiles	Feeds on a variety of vertebrate species	Dominant predator	Data deficient	Data deficient

7 Magpie geese

Large flocks of magpie geese (*Anseranas semipalmata*) are iconic of Kakadu. Magpie geese are a key species in Aboriginal culture, with adults and eggs representing a seasonal food source, as well as a totemic species. Magpie geese are listed as a marine protected species under Commonwealth legislation (*Environment Protection and Biodiversity Conservation Act 1999*).

Climatic and hydrological processes play a key role on the ecology of magpie geese. Magpie geese are concentrated around permanent and semi-permanent waterbodies during the dry season, and disperse to the floodplains following significant rains at the start of the wet season (Whitehead 1998). Specific habitat requirements include *Eleocharis sphacelata* that is used for nesting, and seeds of *Oryza meridionalis* and tubers of *Eleocharis dulcis* that are eaten. The rate, timing and depth of floodplain inundation determine the suitability of vegetation for nesting and the availability of vegetation food sources. Nesting is closely linked to rainfall, and flooding may cause significant egg mortality (Whitehead and Tschirner 1990).

In addition to traditional and recreational harvesting, magpie geese eggs and fledglings may be lost to predation by birds of prey, dingoes, water rats, water pythons and goannas (Frith and Davies 1961). Habitat alteration by feral buffalo may have a significant impact on magpie geese populations, primarily through reduced vegetation cover and changed hydrological patterns.

Table 3-4: Key controls on magpie geese

KEY CONTROLS	ATTRIBUTE			
	NESTING	FEEDING	ROOSTING	ABUNDANCE
Habitat	Seasonally inundated freshwater floodplains	Seasonally inundated freshwater floodplains	Seasonally inundated freshwater floodplains; paperbarks on the fringes of billabongs	Billabongs, seasonally inundated freshwater floodplains
Hydrological	Rate, timing and depth of flooding determines suitability of vegetation for nesting (water depths between 30 and 90cm at nest sites)	Rate, timing and depth of flooding determines abundance of vegetation food source	Extent of flooding determines amount of available roosting habitat	Extent, rate, timing and depth of flooding determines available habitat
Climate	Breed during wet season; nesting success closely tied to rainfall; flooding may cause significant egg mortality	Seasonality determines available food sources (closely linked to hydrology)	Data deficient	Seasonal movements are driven by climatic variation
Geomorphology	Data deficient	Data deficient	Data deficient	Data deficient
Physio-chemical	Vegetation required for nesting has a low salinity tolerance	Vegetation food sources have low salinity tolerances	Vegetation required for roosting is not salinity tolerant	Habitat vegetation has a low salinity tolerance
Biological interactions	Birds and reptiles predate on eggs and goslings	Data deficient	Data deficient	Data deficient

8 Brolgas

The brolga (*Grus rubicundus*), a spectacularly large bird, is another iconic feature of the Kakadu floodplains. This species is a totemic and culturally significant species for indigenous communities.

Brolgas primarily inhabit open wetlands and grassy plains, and may inhabit mudflats to a lesser extent. Brolgas breed during the wet season, when nests composed of a large platform of vegetation are constructed on the seasonally inundated floodplains. Movement from breeding grounds to non-breeding flocking areas occurs as the seasonal floodplains start to dry out.

Brolgas are omnivorous and forage in shallow waters or on damp ground. Brolgas utilise diverse food sourced on a seasonal basis, with the diet including sedge tubers, insects, molluscs and amphibians. Threats to brolgas include predation on chicks and eggs.

Table 3-5: Key controls on brolgas

KEY CONTROLS	ATTRIBUTE			
	NESTING	FEEDING	ROOSTING	ABUNDANCE
Habitat	Seasonal floodplains	Seasonal floodplains; billabongs	Seasonal floodplains	Seasonal floodplains
Hydrological	Rainfall largely determines time of breeding	Data deficient	Data deficient	Population movement influenced by levels of inundation
Climate	Wet season breeding (closely linked to rainfall)	Data deficient	Data deficient	Data deficient
Geomorphology	Data deficient	Data deficient	Data deficient	Data deficient
Physio-chemical	Vegetation required for nesting has a low salinity tolerance	Food sources primarily inhabit freshwater environments	Data deficient	Data deficient
Biological interactions	Predation on eggs and chicks	Omnivorous: sedge tubers, insects, molluscs, amphibians	Data deficient	Data deficient

9 Barramundi

Barramundi (*Lates calcarifer*) is a species of high ecological, cultural and economic significance. From an ecological perspective, barramundi is an important predator and is likely to control freshwater fish community structure and possibly carbon flows in estuarine and freshwater systems. It may therefore be considered a keystone species. Barramundi is the key species targeted by local recreational and commercial fishers, and is of significant iconic and economic importance. From a cultural perspective barramundi represents a key bush tucker species and has other cultural values (totem etc.).

Barramundi ecology is strongly influenced by fluvial hydrology and tidal processes. In addition to its role in controlling geomorphology and therefore habitat structure, freshwater flows and tidal processes ultimately control spawning, feeding and abundance patterns during all life-cycle stages. The SAR catchment has large river discharge and low catchment gradient (and associated high residence time of fluvial flows), which together with the relatively undisturbed condition of floodplain habitats, provide the necessary conditions for maintaining high barramundi abundances.

Spawning occurs in estuarine creek mouths, with spawning site typically in areas with low tidal current velocities. The on-set of spawning is thought to occur immediately prior to the wet season, and is thought to be linked to water temperature. Barramundi are tolerant of a wide range of water quality conditions (i.e. salinity, dissolved oxygen, turbidity), but local fish kills can occur in drying water holes in response to high water temperatures and low dissolved oxygen concentrations. Barramundi is not known to have a highly selective diet, but does vary according to age (i.e. small invertebrates and small fish as juveniles, fish and macro-crustaceans (prawns, crabs etc.) as adults). Prey items can be strongly influenced by flows and water quality conditions.

Table 3-6: Key controls on barramundi

KEY CON-TROLS	ATTRIBUTE			
	SPAWNING	FEEDING	MOVEMENTS	ABUNDANCE
Habitat:	Estuarine creek mouths (D/C Channel)	Adults: Channels & large billabongs Juveniles: Shallow sheltered habitats, including floodplain wetlands, billabongs and margins of creek channels. Larvae often found in supralittoral zone of estuaries, but can also occur in freshwaters.	(see Spawning, Feeding & Abundance) Adults migrate to estuaries to spawn. Juveniles (1+ years) move upstream.	Maintenance of large discharge, with low gradient (slow runoff), and well developed floodplain wetland systems thought to be key controls on overall abundance. Pool size and habitat complexity (presence of large woody debris) thought to be key controls at smaller spatial scales.
Hydrological:	Precedes wet season. Possible cues include higher water temp (~30°C) & lunar cycles	Prey abundance (invertebrates and fish) known to be determined by flow regimes.	See spawning.	In a Qld estuary, significant positive correlation between barramundi catch and summer flow or rainfall (immediately and in subsequent years)[1] Further, recruitment strongly correlated to summer and spring flows[2]
Climate		Data deficient		
Geomorphology	Spawning behind sand bars and mud banks in areas protected by run of ebb & flood tides	Data deficient	Data deficient	Exerts a strong control on habitat structure and therefore abundance.
Physio-chemical	Spawns in saline waters Tolerant of wide range of water quality conditions	Data deficient	Data deficient	Water quality not known to exert a major influence on abundance. Hypoxia, which can occur as pools dry can lead to major fish kills.
Biological interactions	Protandrous hermaphrodites – males change to females after spawning. Not linked to environment but rather age.	Uncertain whether populations are resource limited and therefore whether competition for food and predation are key controls on populations. See also Abundance.	Upstream movements by juveniles possibly linked to higher predation (intra-specific) pressure.	Predation by adults can exert influence on fish community structure, carbon flow & ecosystem functioning.

Data source: Pusey *et al.* 2004, unless indicated 1 = Robins et al. (2005); 2 = Staunton-Smith *et al.* (2004)

10 Saltwater crocodiles

The saltwater crocodile (*Crocodylus porosus*) is an iconic species of Kakadu, and is significant for a number of reasons. Aboriginal people have a unique social and cultural interest in crocodiles, and this species is important bush tucker in terms of meat as well as eggs. Saltwater crocodiles are of ecological importance due to the control that they exert over biological community structure as a dominant predator species. It is protected as a marine and a migratory species under Commonwealth legislation (EPBC Act 1999), and is listed internationally on the IUCN Red List as least concern.

Saltwater crocodiles are found in both tidal and freshwater sections of the river. Breeding occurs in the wet season, with an increase in temperature the trigger for reproductive activities (Webb 1991). Nests are built with vegetation on billabong margins, riverbanks and alluvial floodplains, usually favouring heavily vegetated areas adjacent to tidal water (Grigg and Taylor 1980), and typically in areas with slightly higher relief outside the influence of flood waters. Flooding can be catastrophic to successful nesting. The temperature at which eggs are incubated determines the sex-ratio of hatchlings.

Saltwater crocodiles are opportunistic feeders, with the young feeding on primarily on invertebrates, and the adult diet including a diversity of vertebrates such as birds, fish, wallabies, reptiles. Thermoregulatory behaviour is exhibited, including gaping and basking.

Table 3-7: Key controls on Saltwater Crocodiles

	ATTRIBUTES				
KEY CONTROLS	NESTING	FEEDING	ABUNDANCE	BASKING	MOVEMENTS
Habitat	River banks and alluvial floodplains	Channel, billabongs, floodplains	Channel, billabongs, floodplains	Riverbanks	River channel
Hydrological	Flooding of nests catastrophic to success	Data deficient	Data deficient	Data deficient	Data deficient
Climate	Temperature triggers breeding (Webb 1991); temperature-dependent sex determination	Data deficient	Data deficient	Data deficient	Data deficient
Geomorphology	Data deficient	Data deficient	Data deficient	Data deficient	Data deficient
Physio-chemical	Salinity influences vegetation types, which determines nest site suitability.	Freshwater and brackish	Freshwater and brackish	Data deficient	Freshwater and brackish
Biological interactions	Predation on eggs and hatchlings primarily by reptiles	Opportunistic feeder, feeds on variety of vertebrate species	Dominant predator	Data deficient	Data deficient

11 Mangroves and saltmarsh

Mangroves have extensively colonised the coastal shoreline as well as tidal reaches of the main channel and its tributaries, while saltmarsh communities often occur on the salt-flats adjacent to mangroves. A number of fauna species are known to utilise these habitats, including species that are of recreational and/or commercial value (e.g. barramundi, mangrove jack), as well as species of cultural importance for food, medicine or weapons. Furthermore, mangroves have an important function in coastal stabilisation through protection against coastal erosion and create a buffer against extreme weather events.

Mangrove communities are typically comprised of bands of different species, with the tidal regime and salinity influencing this species zonation.

Table 3-8: Key controls on mangroves and saltmarsh

KEY CONTROLS	ATTRIBUTES	
	MANGROVES EXTENT	SALTMARSH EXTENT
Habitat	Coastal and deltaic	Coastal and deltaic
Hydrological	Tidal regime (e.g. levels, velocities)	Tidal inundation
Climate	Data deficient	Data deficient
Geomorphology	Marine/estuarine sediments	Marine/estuarine sediments
Physio-chemical	Salinity gradients determine species zonations	
Biological interactions	Data deficient	Data deficient

12 Mud crabs

Mud crab (*Scylla serrata*) is a representative marine shellfish species that is of significant fisheries and cultural importance.

It spends most of its life in estuaries, with females migrating offshore in September-October to spawn. The environmental cues responsible for offshore migrations are unknown, but may relate to increasing water temperatures. Larvae (zoea) have a marine phase and require water temperatures of 23-32°C, which may influence the spring (pre-wet) spawning timing. Juvenile crabs settle in estuaries within ~four weeks of hatching. Juvenile crabs seek shelter in mangroves, seagrass (not present in study area) and under rocks, and are tolerant of brackish to full seawater salinity.

Case studies elsewhere demonstrate correlations between crab catches and river flows, although such a relationship may not be as strong in the northern tropics. The ultimate control on this relationship is unknown but may be related to both increased catch-ability of crabs and/or actual increases in their abundance.

The maintenance of extensive areas of mangrove forests is a key to the maintenance of mud crab populations. It is uncertain whether habitat limits population densities and therefore the response of changes in habitat availability results in corresponding linear changes in abundances.

Table 3-9: Key controls on mud crabs

KEY CONTROLS	ATTRIBUTE			
	SPAWNING	FEEDING	MOVEMENTS	ABUNDANCE
Habitat:	Oceanic	Adults: Sheltered estuaries, mud flats and mangrove lined waterways. Females in berry oceanic. Juveniles: Planktonic larval stage in marine waters, settle in nearshore waters, seek shelter under stones and mangrove roots in the upper intertidal areas. Juveniles may also occur on sandbars at the mouth of rivers.	Mating in nearshore areas. Females migrate offshore to spawn. Larvae drift into coastal areas.	Require a combination of marine (offshore benthic) and estuarine (mangroves, mangrove lined creek channel) habitats throughout life-cycle. Data limited for this species, however abundance of congener S. olivacea higher in areas with healthy mangroves than degraded mangrove areas[4].
Hydrological:	Females move offshore in Sept-Oct[1]. Larval survivorship dependent on water temperature (23-32°C) and salinities (seawater)[1], so advantageous to spawn immediately prior to wet season.	Prey abundance (invertebrates) likely to be determined by flow regimes	See spawning – migrate offshore to breed prior to wet season.	Correlations exist between mud crab catches and rainfall and temperature, but tend to be relatively weak in tropical areas[2]. Positive correlations between river flow and mud crab catches[3].
Climate		Data deficient		
Geomorphology	N/A	Data deficient	Data deficient	Exerts a strong control on habitat structure and therefore abundance.
Physio-chemical	Spawns in saline waters.	Data deficient	Data deficient	Relatively euryhaline, but predominantly a marine species. Salinity and temperature control metabolism.
Biological interactions	Data deficient	Uncertain whether populations are resource limited and therefore whether competition for food and predation are key controls on populations	Data deficient	Data deficient

Data source: Kailola *et al.* (1993) unless indicated otherwise. 1 = Hill (1994); 2 = Meynecke (2009); 3 = Loneragan and Bunn (1999); 3 = Robins *et al* (2005); 4 = Walton et al. (2007)

13 Yellow chat

The yellow chat (Alligator Rivers subspecies) (*Epthianura crocea tunneyi*) is a species of conservation significance, listed nationally as vulnerable and under Northern Territory legislation as endangered (Territory Parks and Wildlife Conservation Act 1999).

Yellow chat is a floodplain species, inhabiting saltmarsh and dense grasslands near water sources such as floodplain depressions and channels. Yellow chats typically forage on the ground, and the diet is composed primarily of invertebrates (Higgins *et al.* 2001). Threats to yellow chats include habitat degradation by feral buffalo and pigs.

Table 3-10: Key controls on yellow chat

KEY CONTROLS	ATTRIBUTE			
	NESTING	FEEDING	ROOSTING	ABUNDANCE
Habitat	Saltmarsh and grasslands	Saltmarsh and grasslands	Saltmarsh and grasslands	Saltmarsh and grasslands
Hydrological	Data deficient	Data deficient	Data deficient	Data deficient
Climate	Data deficient	Data deficient	Data deficient	Data deficient
Geomorphology	Data deficient	Data deficient	Data deficient	Data deficient
Physio-chemical	Data deficient	Data deficient	Data deficient	Data deficient
Biological interactions	Data deficient	Forage on invertebrates	Data deficient	Habitat degradation by feral animal trampling

14 Threadfin salmon

Threadfin salmon (*Polydactylus sheridani*) is a representative marine finfish species that is of recreational and commercial fisheries importance.

It spends most of its life in estuaries and nearshore coastal waters, and is thought to spawn in marine areas (site unknown) during the warmer months. The environmental cues responsible for spawning are unknown, but may relate to increasing water temperatures. Little is known about the life history of larvae, although recruitment of juveniles to tidal flats and lower estuaries occurs in October to May, coincident or just after the wet season. It is uncertain whether there is a direct linkage between flow regimes and life-history events. Furthermore, no studies have examined linkages between habitat characteristics and abundances of this species. An increase in habitat (and prey) availability could however lead to increased relative abundance of this species.

Table 3-11: Key controls on threadfin salmon

KEY CONTROLS	ATTRIBUTE			
	SPAWNING	FEEDING	MOVEMENTS	ABUNDANCE
Habitat:	Data deficient Planktonic eggs, likely marine.	Carnivores Feed at or just below water surface in coastal and lower estuary, but also known to take a variety of benthic prey (fish, prawns, crabs).	Juveniles begin to occur on nearshore tidal flats and lower estuaries just after wet season. Adults highly mobile, can move up to 500 km along coastline.	Typically found in coastal or lower estuaries. No studies have examined linkages between habitat and abundances.
Hydrological:	Oct-March, peak in Dec. Possibly linked to water temperature.	Prey abundance (invertebrates and fish) known to be determined by flow regimes.	See Spawning and Habitat.	Recruitment to nearshore areas in October to May, during or just after wet season. Uncertain whether there is a direct link with flows.
Climate		Data deficient		
Geomorphology	Data deficient	Data deficient	Data deficient	Exerts a strong control on habitat structure and therefore abundance.
Physio-chemical	Data deficient	Data deficient	Data deficient	Marine fish, although important nursery areas occur have low salinity (brackish waters).
Biological interactions	Protandrous hermaphrodites – males change to females ~70 – 100 cm length. Not linked to environment but rather age.	Uncertain whether populations are resource limited and therefore whether competition for food and predation are key controls on populations. See also Abundance.	Data deficient	Predators include barramundi, sharks, other salmon and crocodiles.

Data source: Kailola *et al.* (1993) unless indicated otherwise.

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Appendix G: Potential Responses of Key Habitats and Environmental Values

Table 3-12: Potential responses of key habitats to changes in marine and fluvial process drivers

FACTOR		MARINE PROCESSES				FLUVIAL PROCESSES						OTHER CLIMATIC	
		↑ DURATION TIDAL INUNDATION	↑ FREQ. TIDAL INUNDATION	↑ SALINITIES	↑ CURRENT VELOCITY (IN-CHANNEL)	↑ ANNUAL VOLUMES	↓ ANNUAL VOLUMES	↑ FREQ. LARGE FLOODS (INCREASED STORMS)	↑ NO. DRY SPELLS	↑ LENGTH DRY SPELL	DELAYED ONSET WETS	↑ WATER TEMP.	↑ EVAP.
Mangroves	Existing	(+/-) maintenance or increase in habitat for upriver & upper littoral mangroves (-) loss of coastal & lower littoral mangroves due to inundation			(-) bank erosion	↑ (-) reduced sediment retention (scouring); enhanced groundwater; less saline ↓ (-) reduced catchment sediment supply; reduced groundwater; increased salinisation; maintain surface elevation		(-) Possible increase in bank erosion; reduced sediment retention; reduced forest cover; subsidence of ground levels	(+) Possible increase in wet season salinity in upland areas		(?)	(-) reduced productivity	(+/-)
	Adjacent areas landward & upriver	(++) Encroachment of mangroves due to increased habitat availability (assuming sedimentation rates ≥ rate of SLR) (--) Limited colonisation of adjacent areas (assuming sedimentation rates < rate of SLR)			(-) see above	(-) see above		(-) see above	(+) see above.		(?)	(+) see above	(+/-)
Saltmarsh	Existing	(-) Loss due to mangrove encroachment			(-) see above	(+/-) spp. dependent. Similar fundamental responses as mangroves (see above)		(-) see above	(+) Saline tolerant spp, (-) Brackish water spp.		(?)	(+) see above	(+/-)

FACTOR		MARINE PROCESSES				FLUVIAL PROCESSES						OTHER CLIMATIC	
		↑ DURATION TIDAL INUNDATION	↑ FREQ. TIDAL INUNDATION	↑ SALINITIES	↑ CURRENT VELOCITY (IN-CHANNEL)	↑ ANNUAL VOLUMES	↓ ANNUAL VOLUMES	↑ FREQ. LARGE FLOODS (INCREASED STORMS)	↑ NO. DRY SPELLS	↑ LENGTH DRY SPELL	DELAYED ONSET WETS	↑ WATER TEMP.	↑ EVAP.
	Adjacent landward	(++) Encroachment of saltmarsh due to increased habitat availability (assuming sedimentation rates ≥ rate of SLR) (--) Limited colonisation of adjacent areas (assuming sedimentation rates < rate of SLR)			(-) see above	(+/-) see above		(-) see above	(+) see above		(?)	(+) see above	(+/-)
Mudflats	Existing	(-) Increased duration and frequency of inundation and possible change of grass species….etc perhaps increased mangrove encroachment			(-) see above	Unlikely to produce noticeable changes in mudflats (below MHWS)						Unlikely to produce noticeable changes in mudflats (below MHWS)	
Channel (estuarine)	Existing	(-) Increased frequency and volume of tidal over bank flow and increased upstream tidal pressure creating wider channels and extended tidal head			(-) see above	↑ (-) may lead to increased over levee flow (ie breakouts) in the wet leading to an increase in dendritic tidal channels (below MHWS)						Unlikely to produce noticeable changes in channels (below MHWS)	
Channel (FW)	Existing	Unlikely to produce noticeable changes in tidal channel			(-) see above but limited	(+/-) depending on increase or decrease in rainfall. For 2030 with +/- <10% little change for 2070 with +/- 10-20% noticeable ↓ (-) siltation or ↑ (-) scouring						Unlikely to produce noticeable changes in channels (above MHWS)	
Billabongs	Existing	(--) temporary and permanent loss of habitat (possible conversion to saltpan/saltmarsh)				↑ (++) Flushing, scouring, floodplain/river connectivity ↓ (--) Corollary of above. Mortality of salt sensitive species, potential infilling			(-) Delayed flushing, longer period of saltwater inundation			(+/-) Altered flora physio-logical processes	(-) reduced flora habitat suita-bility
Seasonal floodplain	Existing	(--) Loss due to low tolerance of species to saline conditions			n/a?	(-) Reduced sediment retention / sediment supply lowers habitat suitability for flora		(+/-) Increased habitat extent, or reduced sediment retention	(-) Delayed flushing; desiccation of flora; possible increase in salinity; altered phenology			(+/-) Altered flora physio-logical processes	(-) reduced flora habitat suita-bility

FACTOR		MARINE PROCESSES				FLUVIAL PROCESSES						OTHER CLIMATIC	
		↑ DURATION TIDAL INUNDATION	↑ FREQ. TIDAL INUNDATION	↑ SALINITIES	↑ CURRENT VELOCITY (IN-CHANNEL)	↑ ANNUAL VOLUMES	↓ ANNUAL VOLUMES	↑ FREQ. LARGE FLOODS (INCREASED STORMS)	↑ NO. DRY SPELLS	↑ LENGTH DRY SPELL	DELAYED ONSET WETS	↑ WATER TEMP.	↑ EVAP.
Lowland rainforest	Existing	(-) Loss due to low tolerance of species to saline conditions and inundation			n/a?	n/a?		?	(-) Increased desiccation of flora (-/+) Altered phenology			?	(-) reduced flora habitat suitability
Woodlands	Existing	Not likely to be impacted?			n/a?	n/a?		?	(-/+) Altered phenology			No impacts?	No impacts?

+ Positive response
- Negative response
? Unknown response
n/a Not applicable

Table 3-13: Potential response of key EVs to changes in tidal and fluvial processes

ENVIRONMENTAL VALUE		MARINE PROCESSES (INCREASE IN SEA LEVEL)				FLUVIAL PROCESSES					
		↑ DURATION TIDAL INUNDATION	↑ FREQ. TIDAL INUNDATION	↑ SALINITIES	↑ CURRENT VELOCITY	↑ ANNUAL VOLUMES	↓ ANNUAL VOLUMES	↑ FREQ. LARGE FLOODS	↑ NO. DRY SPELLS	↑ LENGTH DRY SPELL	DELAYED TIMING WETS
Pig-nosed turtle		(- -) Spawning, recruitment, feeding sites				(+) Increase habitat due to flushing & scouring	(-) Potential infilling of habitat	(+) Possible increase in habitat availability	(--) Loss of habitat		Delayed hatching
Potadromous fish		(- -) Spawning, recruitment, feeding sites				↑ (++) Increased prey, floodplain habitat connectivity, permanency of offstream waterholes (refugia) ↓ (--) Corollary of above. Prey mortality in offstream wetlands, potential infilling of off-stream waterholes leading to habitat loss			(-) reduced floodplain habitat connectivity		(-) loss of billabong habitat
Freshwater crocodile		(-) loss of habitat, nesting sites				(-) reduced nesting success	?	(-) reduced nesting success	?	?	?
Magpie goose		(--) loss of habitat, nesting sites, food sources				(-) reduced nesting success		(-) reduced nesting success	(-) Loss of habitat		(-) timing of breeding and population movement
Brolga		(--) loss of habitat, nesting sites, food sources				(-) reduced nesting success		(-) reduced nesting success	(-) Loss of habitat		(-) timing of breeding and population movement
Barramundi		(++) Spawning, recruitment sites (--) Reduced nursery habitat & feeding sites			(-) Spawning sites	↑ (++) = Increased prey, floodplain habitat connectivity, permanency of offstream waterholes (refugia) ↓ (-) Corollary of above. Potential infilling of off-stream waterholes leading to habitat loss			(-) reduced floodplain habitat connectivity		(-) loss of billabong habitat

ENVIRONMENTAL VALUE		MARINE PROCESSES (INCREASE IN SEA LEVEL)				FLUVIAL PROCESSES					
		↑ DURATION TIDAL INUNDATION	↑ FREQ. TIDAL INUNDATION	↑ SALINITIES	↑ CURRENT VELOCITY	↑ ANNUAL VOLUMES	↓ ANNUAL VOLUMES	↑ FREQ. LARGE FLOODS	↑ NO. DRY SPELLS	↑ LENGTH DRY SPELL	DELAYED TIMING WETS
Saltwater crocodile		(- -) Loss of nest sites			?	↑ (++) = Increased prey, floodplain habitat connectivity, permanency of offstream waterholes (refugia) ↓ (-) Corollary of above. Potential infilling of off-stream waterholes leading to habitat loss			(-) reduced floodplain habitat connectivity		
Yellow chat		(+/-) Shift in saltmarsh habitat (possible net increase?) (-) Loss of floodplain habitat				?	?	?	(-) Loss of habitat		?
Mud crab		(++) habitat, nursery & adult feeding areas			?	↑ (+) Increase fisheries production (abundance?)		?	?	?	?
Threadfin salmon		(++) habitat, nursery & adult feeding areas			?	?	?	?	?	?	?

+ Positive response

- Negative response

? Unknown response

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Appendix H: Categories, Requirements and Matters for Impact Assessment under the Kakadu National Park Management Plan

Table 2 – Impact assessment procedures

Category	Example	Impact assessment requirements
Category 1 Actions considered likely to have no impact, or no more than a negligible impact, on the Park's environment and natural and cultural values, and on Bininj	• Minor capital works eg maintaining, replacing, repairing or improving existing infrastructure in its present form • Regular/routine ongoing operations to implement prescriptions in this Plan eg patrols/weed control/fire management • Seasonal opening/closing of visitor areas • Issuing permits for regular activities in accordance with this Plan eg land-based tours, camping, research	• No assessment required • Use minimal impact work practices when implementing actions
Category 2 Actions considered likely to have more than a negligible impact, but not a significant impact, on the Park's environment and natural and cultural values, and on Bininj	• Moderate capital works eg new infrastructure or moderate expansion/upgrade of existing infrastructure • Rehabilitation of heavily eroded sites • Developments for approved existing tourism activities that do not require major works eg small safari camps • Minor new operations or developments to implement prescriptions in this Plan • Tour operator accreditation system	• Assessment by Park staff, proponent, or independent expert • Assessment in accordance with procedures outlined in Table 3 and approved by Director and Board
Category 3 Actions considered likely to have a significant impact on the Park's environment and natural and cultural values, and on Bininj	• Major capital works eg new major infrastructure or major expansion/upgrade of existing infrastructure • Major new operations or developments to implement prescriptions in this Plan • Major/long-term changes to existing visitor access arrangements • Large-scale mine rehabilitation • Expansion of the Jabiru township • New types of commercial activities • New or major expansion of Bininj living areas	• Director will consider whether action should be referred for consideration as a 'controlled action' under the EPBC Act • If action referred and Minister decides it is a controlled action no assessment required by Park staff • If action not referred, or referred and Minister decides it is not a controlled action, assessment as for Category 2

Table 3 – Environmental impact assessment matters and considerations

Matters for assessment	Considerations include, but not limited to
1. Environmental context (a) What are the components or features of the environment in the area where the action will take place?	• Species, ecological communities in the park-wide and regional context • Matters of national environmental significance • Cultural features • Heritage features • Socio-economic values including Bininj uses and interests • Tourism and recreational values • Aesthetic/landscape values • Scientific reference areas
(b) Which components or features of the environment are likely to be impacted?	• Short- and long-term impacts on- and off-site
(c) Is the environment which is likely to be impacted, or are elements of it, sensitive or vulnerable to impacts?	• Species, ecological communities • Matters of national environmental significance • Cultural values (including sacred sites) • Heritage values • Tourism and visitor experience • Bininj interests, in particular relevant lease conditions • Cumulative impacts from a range of activities across the park on the environment or its elements • Uniqueness of elements within the park-wide and regional context
(d) What is the history, current use and condition of the environment which is likely to be impacted?	• Comparison with condition of similar sites elsewhere in the park
2. Potential impacts (a) What are the components of the action?	• Include associated infrastructure and stages
(b) What are the predicted adverse impacts associated with the action including indirect consequences? (c) How severe are the potential impacts? (d) What is the extent of uncertainty about potential impacts?	• Include indirect and off-site impacts • Consider scale, intensity, timing, duration and frequency
3. Impact avoidance and mitigation Will any measures to avoid or mitigate impacts ensure, with a high degree of certainty, that impacts are not significant?	• Include any alternative sites
2. Significance of impacts Considering all the matters above, is the action likely to have a significant impact on the environment?	• If yes, the Director will consider whether action should be referred for Ministerial consideration under the EPBC Act

Note: this is a guide only – the detailed environmental impact assessment process is set out in the Manual of Procedures.

Source: Director of National Parks (2007)

Reference

Director of National Parks (2007) *Kakadu National Park Management Plan 2007-2014*. Director of National Parks.

Appendix I: Catchment (Rainfall/Runoff) Model

South Alligator River Catchment Model

Introduction

The freshwater flows and sediment loads from the 11,700 km^2 South Alligator River catchment were modelled using the WaterCAST catchment modelling framework (Argent *et al,* 2005; Argent et al, 2008 eWater CRC, 2009). The model was developed to assess potential climate change impacts on catchment flows, wet periods and dry periods, and to provide time series inputs to receiving water models. Limited data was used to create and calibrate the model, therefore the results of any one model scenario should not be viewed in isolation but in comparison with other scenarios.

WaterCAST Catchment Model Framework

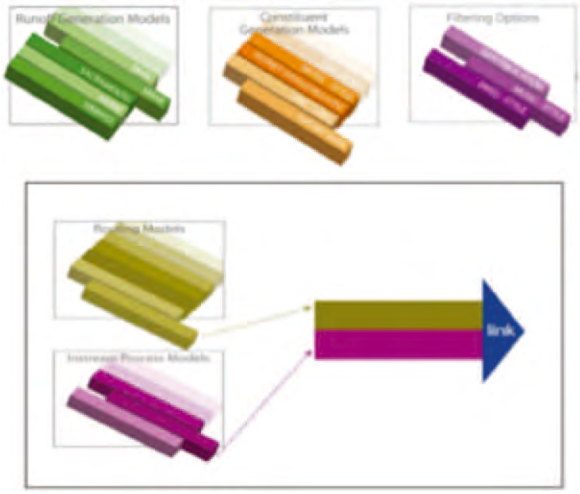
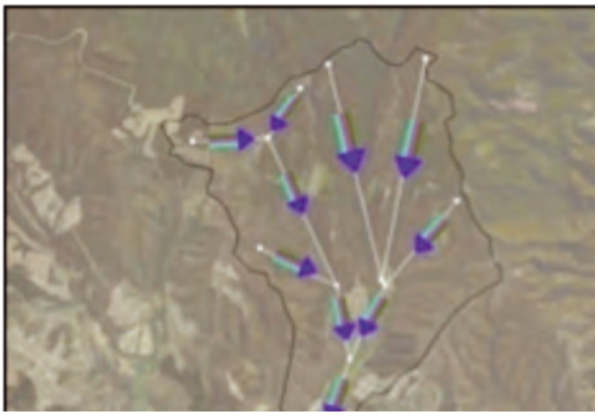
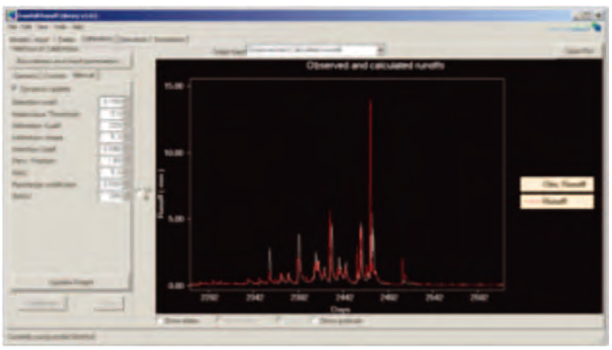
The WaterCAST modelling framework provides the ability to simulate catchment characteristics and responses, in addition to evaluating the impacts of land use change, changes due to climate drivers and implementation of best management practices. The WaterCAST framework is not one model, but a framework in which groups of different models can be selected and linked such that the most suitable model to describe a particular aspect of the catchment can be used.

The underlying data within the model is some spatial description of the catchment, whether simply a subcatchment map or one derived from a digital elevation model. These subcatchments are either manually or automatically joined together via a node-link network that describes the hydrologic connectivity of the system being modelled. Functional Units (FUs) are used by the model to describe individual catchment characteristics such as soil types or land uses. Individual climate, hydrologic and pollutant export models can be assigned to each FU. The basis steps to WaterCAST model construction are provided in Table 1.

The WaterCAST modelling framework requires a number of data sets including:

- A digital elevation model (DEM) or subcatchment map for subcatchment delineation;
- A land use map to provide a basis for functional unit definitions;
- Climate data (daily rainfall and evaporation data);
- Water quality data and/or EMC/DWC data for pollutant export model parameterisation; and
- Hydrological data for model calibration.

Table 1: Development of a WaterCAST catchment model

 Step 1 – A Spatial Description of the Catchment	 Step 2 – Construction of a Node-Link Network
 Step 3 – Definition of Functional Units (Land Uses) land use data is used to describe the “Functional Units” (FUs) within each subcatchment where different FUs have particular runoff and constituent generation characteristics.	 Step 4 – Selection of Node and Link Models applicable to each FU.
 Step 5 – Node and Link Models Describe the Catchment and climate data applied	 Step 6 – Model Parameterisation and Calibration

South Alligator River WaterCAST Model Data

Subcatchment delineation

The 11,700 km^2 South Alligator River catchment was delineated into subcatchments using a 90m digital elevation model based on data from the International Centre for Tropical Agriculture (CIAT) (Jarvis *et al,* 2006.). Northern sections of the model too flat to be delineated using the DEM were constructed manually using catchment, river and wetland mapping (Parks Australia 2008) as catchment delineators. This was undertaken to ensure that model outputs could be extracted from a wide range of upstream boundary locations for the receiving water model. Subcatchments were linked via a node link network as shown in Figure 1.

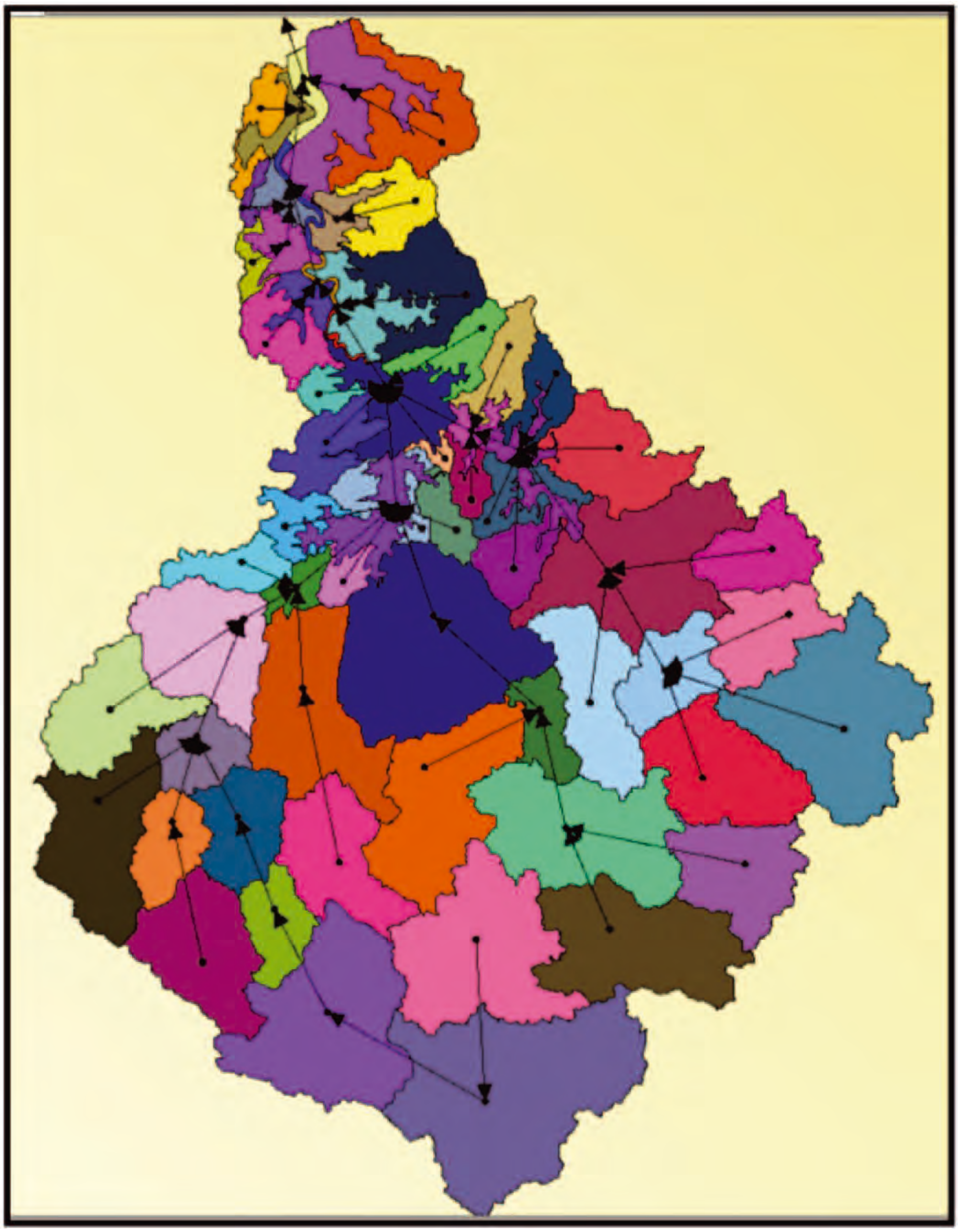


Figure 1: South Alligator River WaterCAST Model

Climate data underpinning the catchment model was sourced from the Bureau of Meteorology (BOM) and the Northern Territory Department of Natural Resources, Environment and the Arts (DNRE&A). A total of 14 rainfall stations (Table 2) were chosen based on proximity to the South Alligator River catchment and the availability of data (pre 1990). A consistent 10 year period between 1980-1990 was chosen for current condition modelling and scenario generation. Daily rainfall data from the 14 rain gauges was assigned to a 5km x 5km grid covering the model domain using the Inverse Distance Weighting (IDW) spatial interpolation method shown in Equation1. Briefly, the geographical distance between each grid point and each rain gauge station was calculated using the Pythagorean Theorem and a weight applied to each rain gauge based on the distance to each point in the 5 km grid.

$$w = \frac{\frac{1}{d^2}}{\Sigma \frac{1}{d^2}}$$

Equation 1

Where:
w = rain gauge weighting; and
d = distance between grid point and rain gauge.

Empty gridded rainfall files were then populated with a rainfall time series by multiplying the daily rainfall values by the weighting value of the rain gauge. If data from a specific gauge was not available on a specific time step (i.e. quality flag -9), the weights from the other intersecting gauges were increased proportionally to bring the total weight to 1.

The above process resulted in a daily rainfall grid across the entire model catchment from the 1st January 1980 to 31st December 1989. This data is in the 5 column rainfall time series format appropriate for automated input to the WaterCAST model. The process was largely implemented in the freeware Matlab clone Octave. Daily potential evapotranspiration data (PET) data was based on monthly evaporation data, sourced from the BOM PET atlas and represents monthly averaged PET values across a 10km x 10km grid. This data was automatically imported into the WaterCAST framework.

Table 2: Rain gauge data

STATION NUMBER	NAME	EASTING	NORTHING
14091	EL SHARANA	230906.4	8503440
14176	MUNMALARY	228261.2	8619452
14179	GOODPARLA	204777.1	8509438
14224	WANDIE CREEK	196942.9	8471942
14228	CORONATION HILL	240658	8496341
14230	KAPALGA CSIRO	248160	8595195
8140018	Katherine River at Sleizbeck	266854	8477192
8140021	Katherine River at Upper Reaches	305116	8509131
8140159	Seventeen Mile Creek At Upper Catchment	225684	8440351
8200046	Deaf Adder Creek At 8 Miles U/s Gs	298611.3	8551794
8200052	South Alligator River At Coronation Hill	240501.6	8497729
8200056	South Alligator River At At Dinner Creek	240127.6	8489164
8210009	Magela Creek	272053.1	8598968
8210017	Magela Creek Plains At Jabiluka Billabong	268944.3	8621482

Hydrological Parameterisation

Hydrological parameterisation of the model was based on daily modelled flows to gauge G8200045 (South Alligator River at El Sherana). Parameterisation was undertaken using the Rainfall Runoff Library using the Rosenbrock search method (Podger 2004) with the primary objective function being the maximisation of the Nash Sutcliffe (1970) criteria for modelled vs. predicted monthly flows, with the secondary objective function criteria to match the flow duration curve.

A number of other gauges were considered for model parameterisation, however inconsistent availability of concurrent gauge data (flows) and rainfall data limited the use of other gauges for parameterisation. Gauges associated with floodplain location in the northern section of the model were not considered appropriate for parameterisation of the geologically different southern parts of the model. Model parameters and performance is shown in Table 3 and Figure 3.

Table 3: Hydrological Parameters

HYDROLOGIC PARAMETER	VALUE
Baseflow Coefficient	0.3
Impervious Threshold	1
Infiltration Coefficient	288
Infiltration Shape	3
Interflow Coefficient	0.01
Pervious Fraction	1
Rainfall Interception Storage Capacity (RISC)	1.2
Recharge Coefficient	1.0
Soil Moisture Store Capacity (SMSC)	252

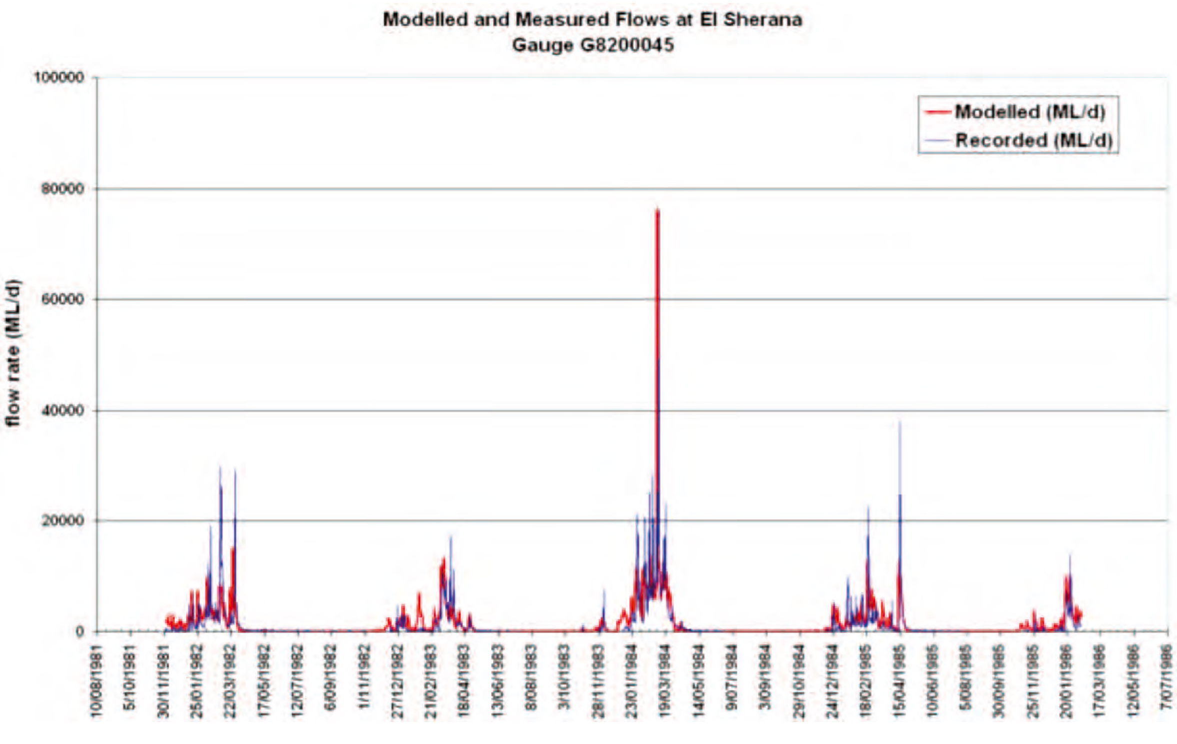


Figure 3: Modeled vs. measured flows at El Sherana Gauge G8200045

The Nash Sutcliffe (1970) value for modelled vs. predicted monthly flows is 0.85. The correlation between monthly modelled and measured flows is shown in Figure 4. The model appears to predict high flow months better than low flow months where there is a tendency for over prediction. The extent of this over prediction is investigated by plotting the double mass curve (Grayson et al, 1996) of modelled and measured flows. The double mass curve of the cumulative sums of modelled flows and measured flows is shown in Figure 5. This curve shows the degree of correlation between the measured and modelled flows and shows a constant relationship over 5 seasons (1981–1986) and shows a relatively constant relationship and highlights the relative impact of over predicting low flow months (~10% model error).

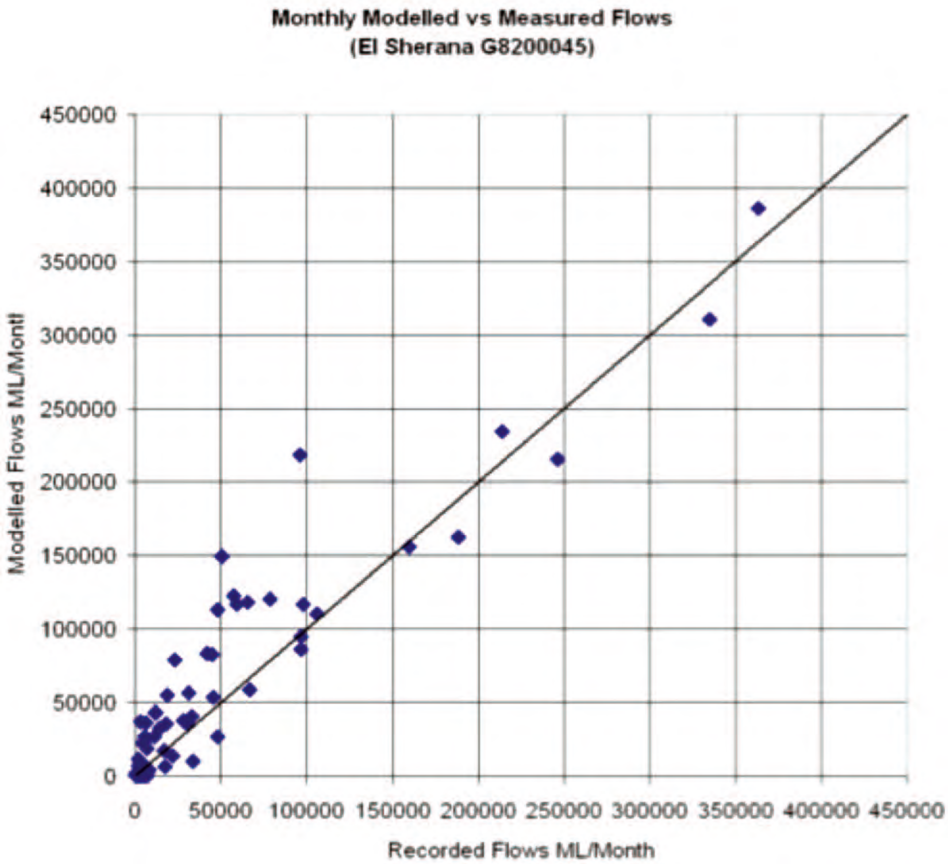


Figure 4: Monthly modeled vs. measured flows at El Sherana Gauge G8200045

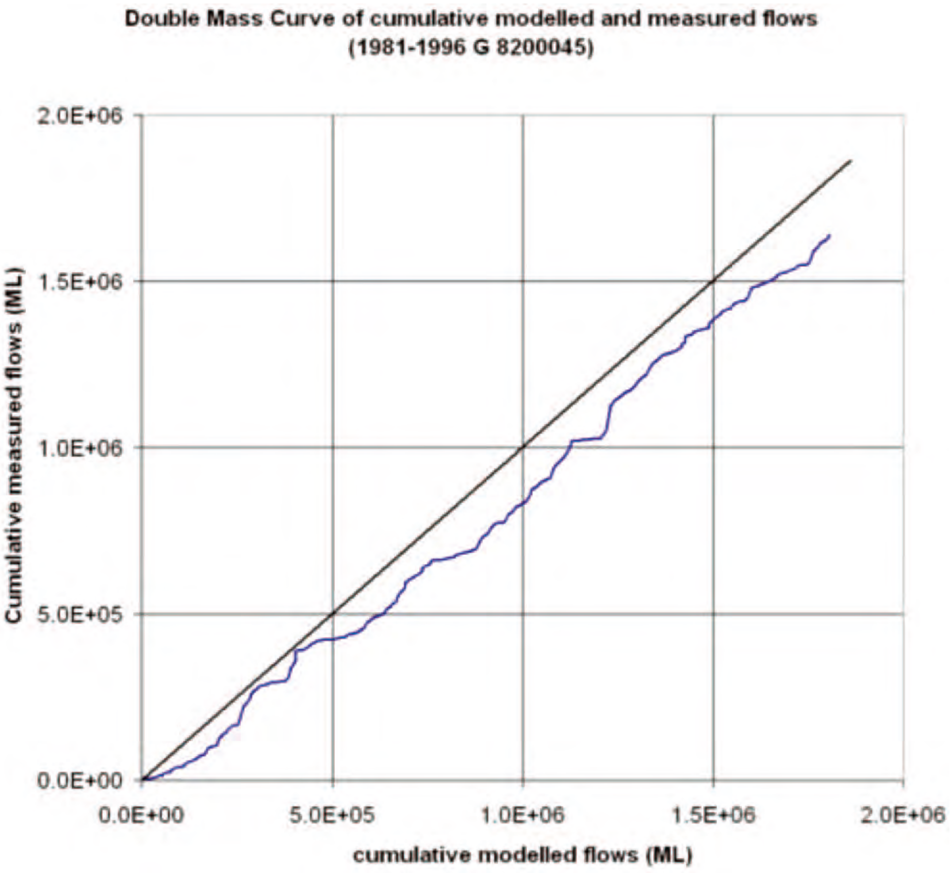


Figure 5: Double mass curve of modelled and measured flows at El Sherana Gauge G8200045

Model Functional Units

A geological map (Parks Australia 2008) describing approximately 38 soil classes was used to create the functional units for the model. These 38 classes were was simplified to 5 broad classes based as shown in Table 4. The reason for using broad soil classifications was to attempt to correlate water quality data to soil types and thus provide an estimate of sediment export.

Table 4: Land Use Classes and Areas used for the WaterCAST Model

CLASS	AREA (KM^2)	PERCENTAGE OF TOTAL AREA (%)
Granite	609	5%
Mud/Silt/Clay	2117	18%
Sand	2806	24%
Sandstone	5196	45%
Soils*	910	8%
Total	**11,638**	100%

* All outstanding soil classes lumped into 1 class

Model Scenarios

Ten model scenarios were generated for the WaterCast Model corresponding with those outlined in Table 5. These scenarios were modelled by direct scaling the daily rainfall and PET data to reflect various projected climate change scenarios. These percentage change figures represent those for Darwin as published by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2000; 2007) and interpreted by CSIRO in Climate Change in Australia (CSIRO, 2007).

Table 5: WaterCAST model Scenarios

IPCC EMISSIONS SCENARIOS	PROJECTED ANNUAL RAINFALL CHANGE (%)	PROJECTED ANNUAL PET CHANGE (%)
Current Conditions	-	-
2030 A1B 10P	-7	+2
2030 A1B 50P	0	+3
2030 A1B 90P	+6	+5
2070 B1 10P	-11	+3
2070 B1 50P	-1	+5
2070 B1 90P	+10	+8
2070 A1FI 10P	-21	+7
2070 A1FI 50P	-1	+10
2070 A1FI 90P	+20	+15

Model Results

Modelled average annual discharge volumes for the basecase and climate change scenarios are provided in Table 6 and shown graphically in Figure 7. The absolute values presented in Table 6 should be interpreted with caution due to the limited hydrological calibration data described above used to parameterise the model.

Table 6: WaterCAST Modelled Average Annual Flows (1980–1989)

IPCC EMISSIONS SCENARIOS	AVERAGE ANNUAL RUNOFF VOLUME, GL	PERCENTAGE CHANGE FROM CURRENT CONDITIONS
Current Conditions	3682	-
2030 A1B 10P	3202	-13%
2030 A1B 50P	3670	0%
2030 A1B 90P	4083	11%
2070 B1 10P	2328	-37%
2070 B1 50P	3583	-3%
2070 B1 90P	5077	38%
2070 A1FI 10P	2942	-20%
2070 A1FI 50P	3595	-2%
2070 A1FI 90P	4359	18%

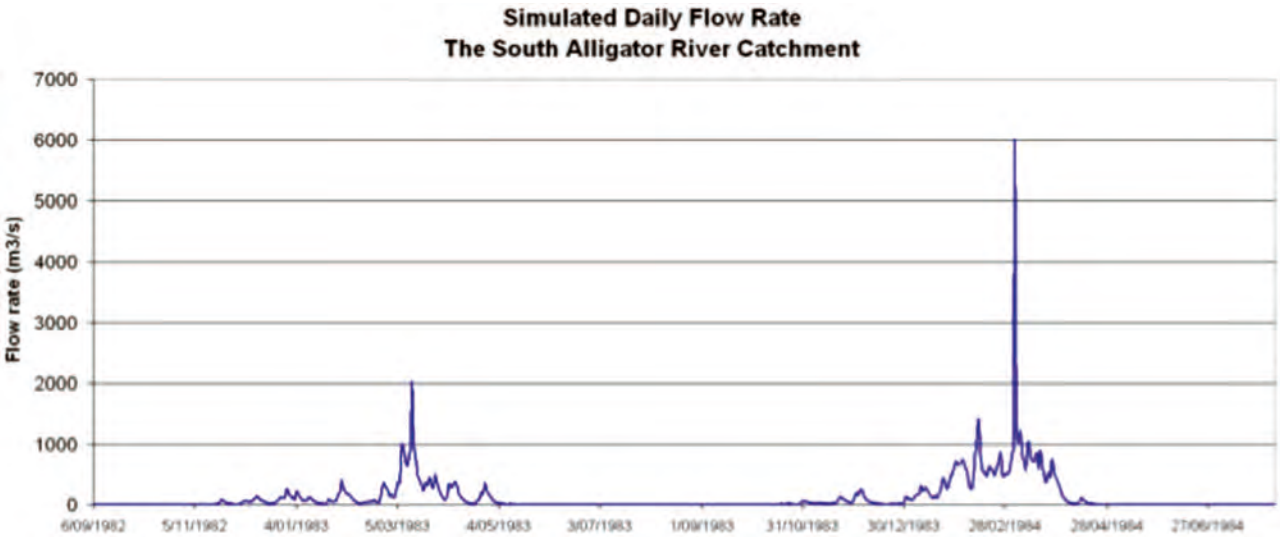


Figure 6: Simulated Daily Flows, South Alligator River

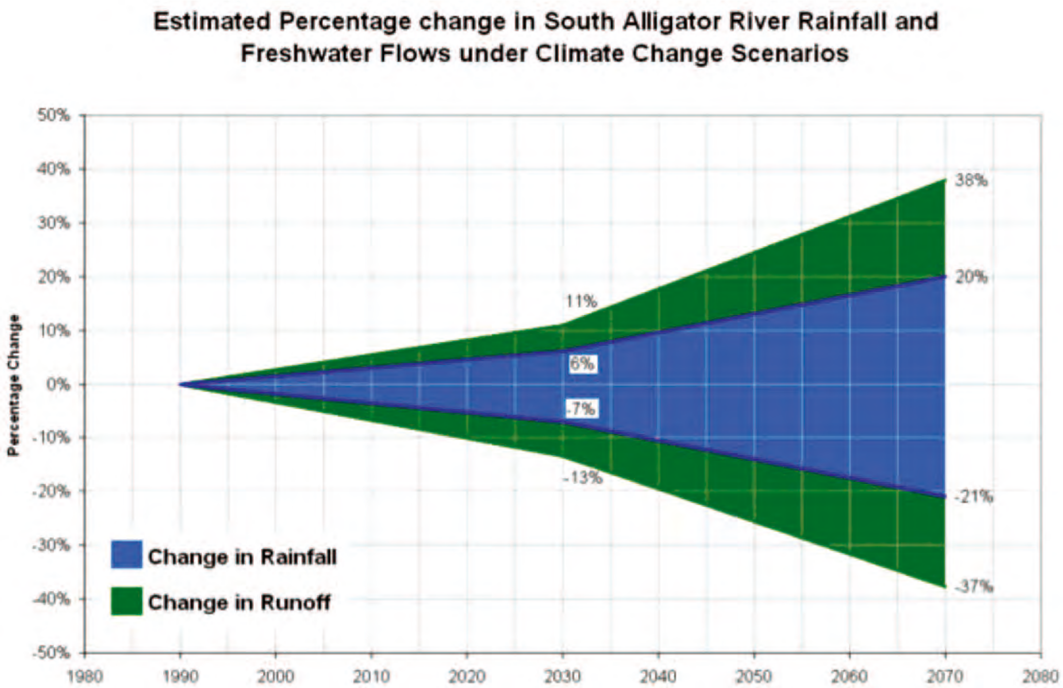


Figure 7: Estimated change in runoff with predicted change in rainfall

Greater reliance may be placed in the percentage differences between scenarios rather than absolute values presented in Table 6 because the model scenarios deal specifically with sensitivity of model output to climate drivers only. Model results indicate that the estimated percentage change figures due to climate change may be consistent across a range of annual flows indicating relative percentage change insensitivity to total estimated basecase flows as shown in Figure 8. This plot shows the range of average annual flow volumes predicted by the model over a 10 year period and shows that as flows increase, the percentage increase or decrease (spread) in the data changes proportionally.

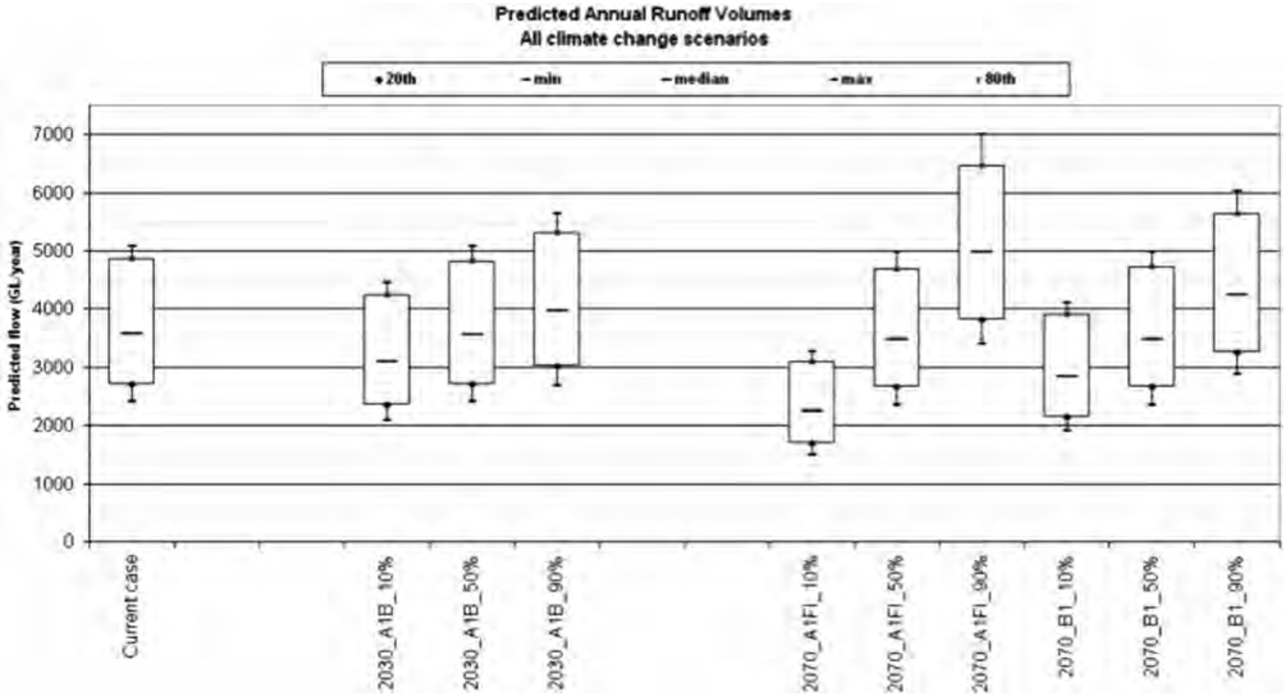


Figure 8: South Alligator River WaterCast Model

Wet spells, dry spells and high flow frequency and duration

Modelled daily flows from the upper South Alligator River catchment have been used to generate information on the duration and frequency of wet and dry periods. The daily modelled flows have been generated by direct up and down scaling of rainfall and evaporation data and therefore do not directly translate to less or more days of runoff, but rather increases or decreases in runoff volume. To assess the potential impacts of the modelled changes to runoff volume on duration and frequency of wet and dry periods, the daily modelled flows have been passed through a theoretical storage which has been configured such that the storage fills with inflows from modelled daily flows and drains via a percentage release. The percentage release for all scenarios was selected by modelling the current conditions and allowing the theoretical storage to empty by November following a wet season. The outflow time series from the theoretical storage are used for all dry spell, wet spell and flood flow duration and frequency analysis.

Dry spells

Dry spells are defined as continuous periods of wet conditions where daily flows are less than a particular threshold. The threshold was determined as the median flow rate of all May-October flows. The threshold is approximately 400ML/day as shown in Figure 9 and the projected increase or decrease in dry spell frequency and duration is shown in Table 7. The table shows that under dryer climate change scenarios, both the duration and frequency of dry spells may increase and under wet climate change scenarios the duration of dry spells is likely to decrease.

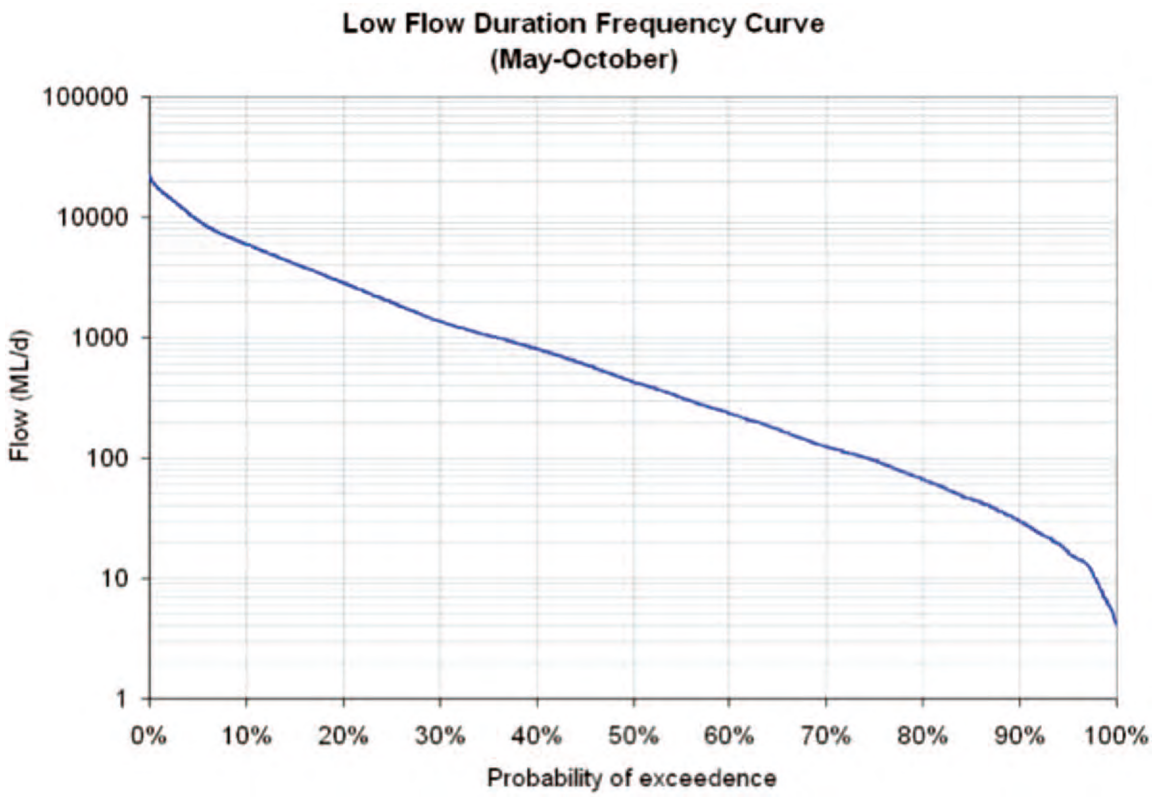


Figure 9: Low flow duration frequency

Table 7: Dry Spells

IPCC EMISSIONS SCENARIOS	DRY DAYS PER YEAR	PERCENT CHANGE IN DRY DAYS	NUMBER OF DRY SPELLS IN 10 YEARS	DRY DAYS PER SPELL
Current Conditions	102		11	93
2030 A1B 10P	107	4%	11	97
2030 A1B 50P	103	0%	11	93
2030 A1B 90P	97	-5%	12	81
2070 B1 10P	120	18%	13	92
2070 B1 50P	103	1%	11	94
2070 B1 90P	89	-13%	11	81
2070 A1FI 10P	110	8%	12	92
2070 A1FI 50P	103	1%	11	94
2070 A1FI 90P	94	-8%	11	86

Wet Spells

We spells are defined as continuous periods of wet conditions where daily flows exceed a particular threshold. The threshold was determined as the median flow rate of all November-April flows. The threshold is approximately 14000ML/day as shown in Figure 10 and the projected increase or decrease in wet spell frequency and duration is shown in Table 8. The table shows that under dryer climate change scenarios, the duration of wet spells may decrease significantly and under wet climate change scenarios the duration of wet spells may increase moderately.

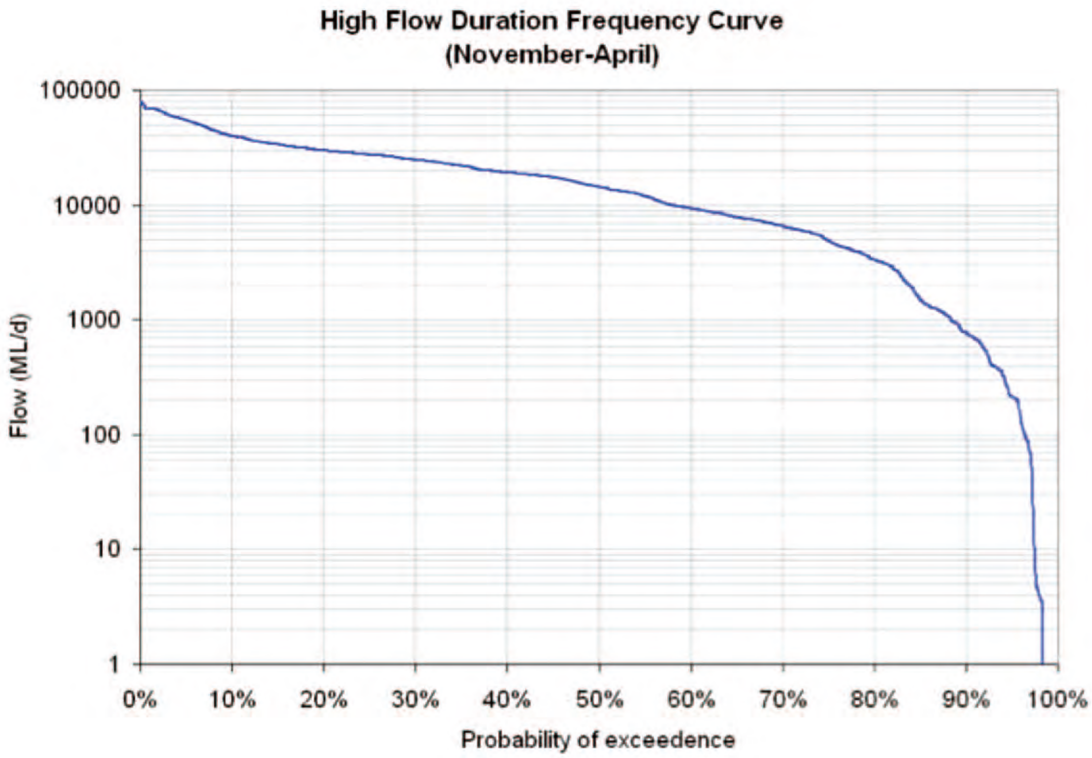


Figure 10: High flow duration frequency

Table 8: Wet Spells

IPCC EMISSIONS SCE-NARIOS	WET DAYS PER YEAR	PERCENT CHANGE IN WET DAYS	NUMBER OF WET SPELLS IN 10 YEARS	WET DAYS PER SPELL
Current Conditions	98		11	89
2030 A1B 10P	89	-9%	11	81
2030 A1B 50P	98	0%	11	89
2030 A1B 90P	105	7%	11	95
2070 B1 10P	64	-32%	12	53
2070 B1 50P	96	-3%	11	87
2070 B1 90P	116	18%	12	96
2070 A1FI 10P	83	-12%	14	60
2070 A1FI 50P	96	-2%	11	87
2070 A1FI 90P	108	11%	11	98

Large events

Large events are defined for this study as those exceeding 60,000 ML/day, or about 1.5% of all daily flows. The frequency and duration of these rare events is difficult to quantify statistically over such a short modelling time frame (10 years), however the table below shows indicatively how the occurrence of these events may be impacted by climate change. Table 9 shows the typical frequency and duration of high flow events in the 10 years of model record under current conditions and climate change scenarios. Typically, under dry climate change scenarios large event frequency and duration is significantly reduced and under wet climate scenarios large event frequency and duration significantly increases.

Table 9: Large Events

IPCC EMISSIONS SCENARIOS	HIGH FLOW EVENTS IN 10 YEARS	NUMBER OF DAYS FLOW EXCEEDS 60,000 ML/D	AVERAGE EVENT DURATION (DAYS)
Current Conditions	3	59	20
2030 A1B 10P	2	15	8
2030 A1B 50P	3	56	19
2030 A1B 90P	3	90	30
2070 B1 10P	0	0	0
2070 B1 50P	3	51	17
2070 B1 90P	5	145	29
2070 A1FI 10P	1	4	4
2070 A1FI 50P	3	53	18
2070 A1FI 90P	5	107	21

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Appendix J: Coastal (Cyclonic Storm Surge) Model

Memorandum

Job:	Kakadu National Park Storm Tide	**Job No:**	J0902
Subject:	Description of Methodology and Results	**Doc ID:**	MO001B
Date:	02/04/2009		
To:	Malcolm Andrews / BMT WBM	**Status:**	Final
From:	Bruce Harper / SEA	**Mode:**	Email

Introduction

This memorandum describes statistical modelling of storm tide risk for the Kakadu National Park coastal margins in the Northern Territory, as requested by BMT WBM Pty Ltd in January 2009, as part of a Commonwealth Department of Climate Change and Energy Efficiency Coastal Vulnerability Assessment.

It is understood that estimates of storm tide risk are required for assessing potential climate change impacts on the Alligator River coastal floodplains and environs in the Northern Territory, approximately 180km east of Darwin (refer Figure 1).

Figure 1: The study site.

SCOPE AND METHOD

With reference to SEA's email of 13/01/2009, a storm tide assessment has been undertaken utilising components of an existing storm tide modelling system (SEA 2005) that extends across the Kakadu region. This provides a parametric storm tide modelling capability that has been combined with regional tropical cyclone statistics developed for the nearby Darwin storm tide risk study (SEA 2006). Climate change sea level rise and cyclone climatology changes were then agreed, as described later, providing three scenarios: "present", "2030" and "2070" climates.

Definitions

Storm tide is a prolonged rise in ocean levels most notably caused by a severe meteorological event such as a tropical cyclone passing close by or crossing a shallow-water coastline (Harper 2001). It is principally the result of extreme surface wind stress and low surface pressures on the ocean surface, whereby the cyclone generates a long-wave disturbance (the storm surge) and also associated short-period surface wind-waves. The storm tide mean water level (MWL) is considered as being made up of the combined effects of the astronomical tide, the storm surge magnitude and the wave setup magnitude (refer Figure 2). It is an absolute level, referred here to Australian Height Datum (AHD). Because the astronomical tide varies (up to the Highest Astronomical Tide, or HAT), the total storm tide also varies with the tidal range. Additionally, wave runup can intermittently reach higher vertical levels if the coastline is fronted by dunes or cliffs and until the coastal margin becomes submerged.

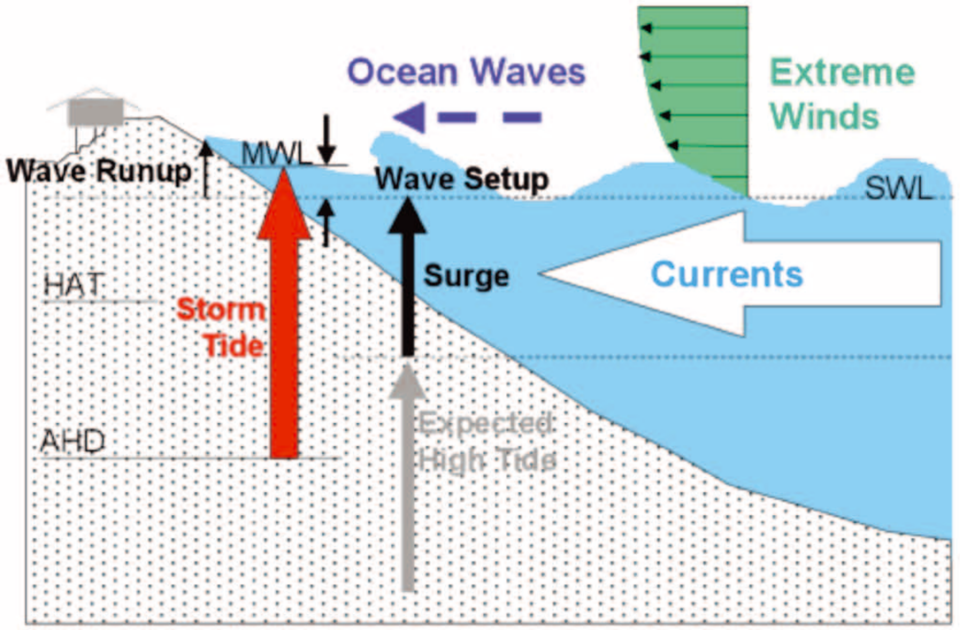

Figure 2: Water level components of an extreme storm tide (after Harper 2001).

Model Details

SEA's SATSIM probabilistic storm tide model has been used here to investigate the long term probability of total storm tide levels for a wide range of tropical cyclone track and intensity scenarios near the Kakadu region. The model has been based on the parametric storm tide model previously developed for use in the NT storm tide prediction system (SEA 2005) and is similar to the probabilistic model developed for the NT Emergency Services (SEA 2006) used to estimate storm tide probability near Darwin.

The present model differs mainly in terms of the available spatial resolution, which is 2.78 km rather than the 0.560 km available in the higher resolution model. The Kakadu Park site is located in the south-east corner of Van Diemen Gulf, which is semi-enclosed by the Cox Peninsula to the east and north, and Melville Island to the north-west.

Figure 3 illustrates the "B grid" area modelled by the parent hydrodynamic model at the 2.78 km resolution. An outer "A grid" was also utilised, with a resolution of 13.4 km, to capture broadscale forcing. The hydrodynamic model used for constructing the SATSIM parametric response was MMUSURGE (refer Harper 2001) and spectral wave modelling was undertaken using ADFA1 (e.g. Young 1987).

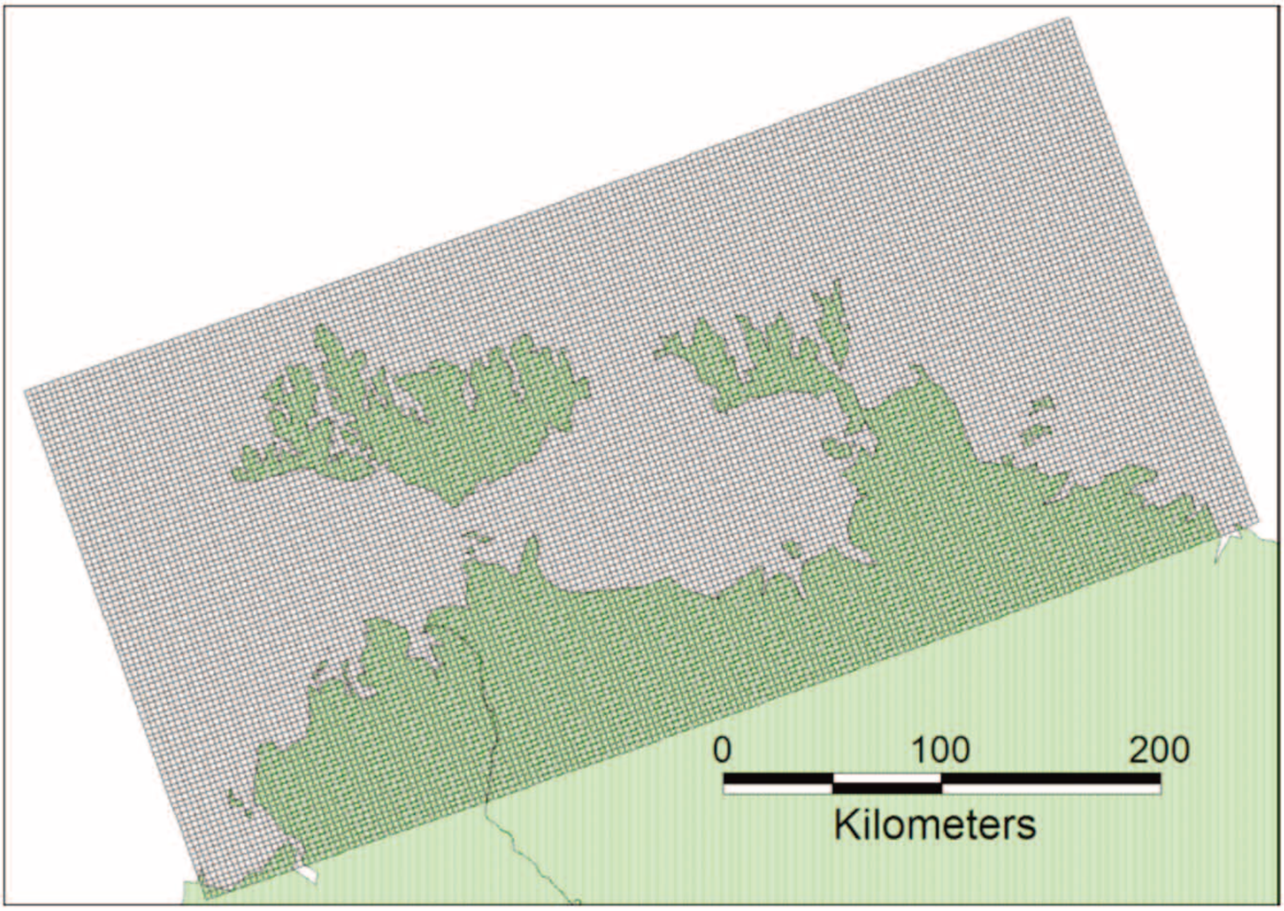

Figure 3: The region modelled by the hydrodynamic model.

The parametric storm tide model provides predictions only at defined coastal points on the hydrodynamic model grid, as shown detailed in Figure 4 for the Kakadu coastal region. Figure 5 provides further detail of the hydrodynamic model representation of this area. Importantly, there were limitations to the accuracy of the land elevation and sea depths available when the parent model was constructed (refer SEA 2005). As a result, the model utilised here assumes that most of the coastal area is "non-floodable land", contrary to the fact that there are extensive marshlands. However, the East and South Alligator river estuaries are sufficiently large to have been modelled to some extent, such that there are two locations available further up-river that feature in the parametric model. The model assumption of land rather than marshy areas will tend to likely overpredict the amplification of storm tide in these up-river locations and also at the coastline. Meanwhile, omitting the inundation modelling of marshy plains can sometimes underpredict the peak elevations attainable at locations further inland. Overall, however, the model results at the coastline are expected to be reasonably representative of the coastal margin.

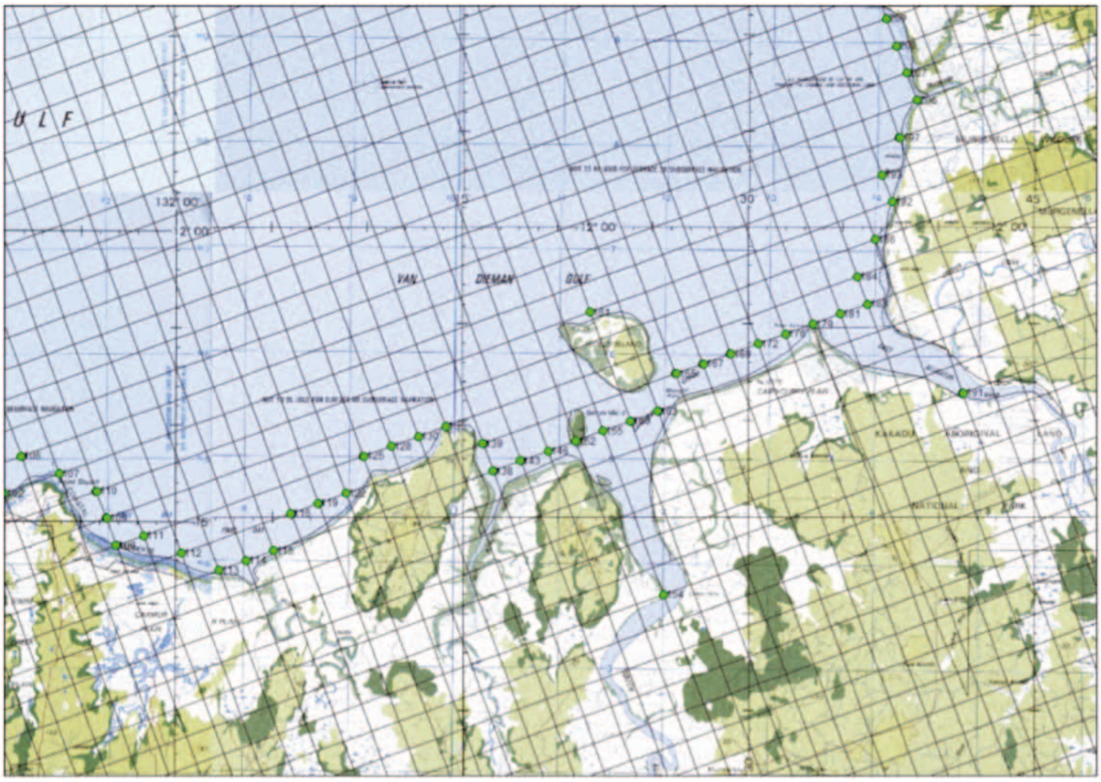

Figure 4: Coastal points available from the parametric/statistical model

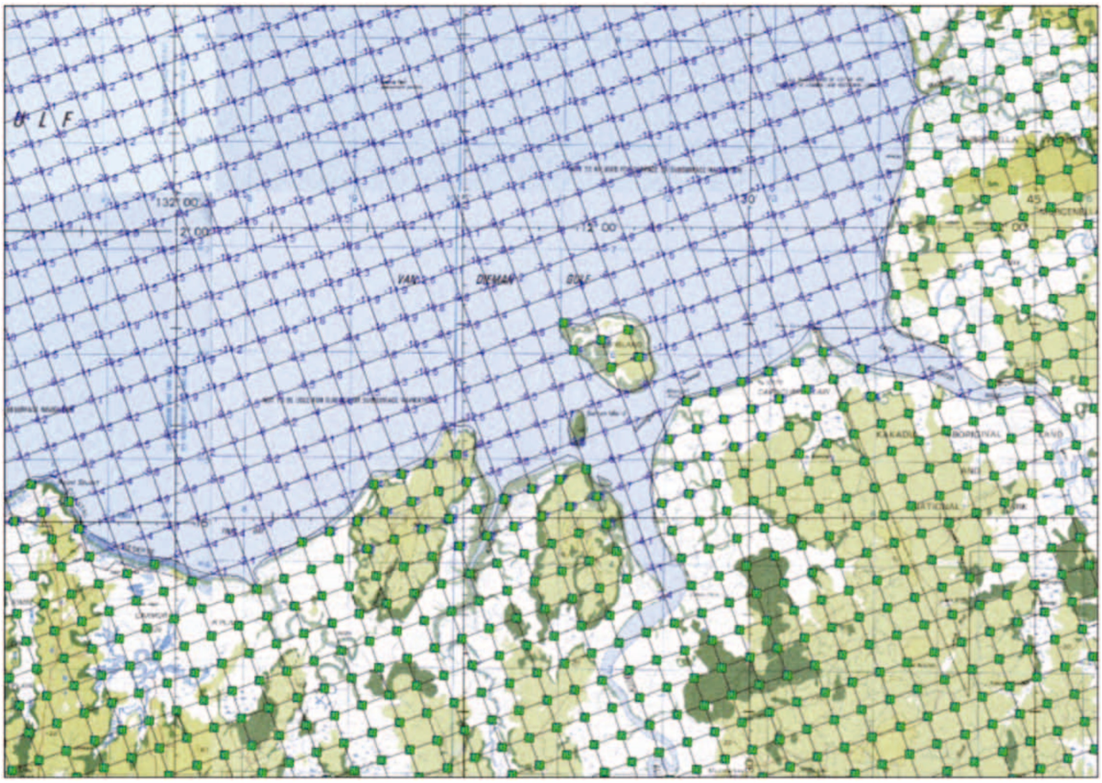

Figure 5: Depths to MSL and “land” as defined in the parent hydrodynamic model.

An additional feature of the parametric model is that it is sensitive to the nominated “dune crest” elevation and will accordingly modulate the effect of breaking wave setup. For this study, general guidance on the applicable levels has been taken from Woodroffe and Mulrennan (1993), which suggests that typical “coastal margins” near the Mary River (immediately to the west) are near HAT. The model context assumes that there will be no morphological response to any changes in Mean Sea Level (MSL).

Astronomical Tide Variation

In the absence of any better information, the model uses Darwin Harbour tidal constituents as the primary tidal reference for the area, modified by a simple range ratio derived from analysis of the National Tidal Centre 8-constituent numerical tidal model of the area (refer SEA 2005). The resulting HAT tidal plane at the Kakadu coastal margin is estimated to be about 2.8 m MSL (assumed AHD). This represents a significant reduction relative to Darwin, which is 4.0 m AHD.

Regional Tropical Cyclone Climatology

The SATSIM model utilises historical tropical cyclone track and intensity data obtained from the Bureau of Meteorology and as modified by Harper *et al.* (2008). It utilises all known tropical cyclones within 500 km of Darwin (refer Figure 6) for the period 1959/60 to 2005/06, this being 100 storms within a 47 year period. A 500 km radius captures all storms within a nominal 24 hour reach of Darwin and is deemed relatively representative also of the Kakadu National Park area.

The historical period covers the advent of satellite detection in the region, although consistency in intensity estimation was typically not established until the late 1970s. There remain some doubts as to the homogeneity of intensity estimates as a result and even post-1970 estimates may be in error. However, attempts have been made to compensate for this likely effect by ensuring that the statistical intensity analyses are conservative. The veracity of this has been supported by comparisons between model simulated peak wind speeds and regional long term measurements.

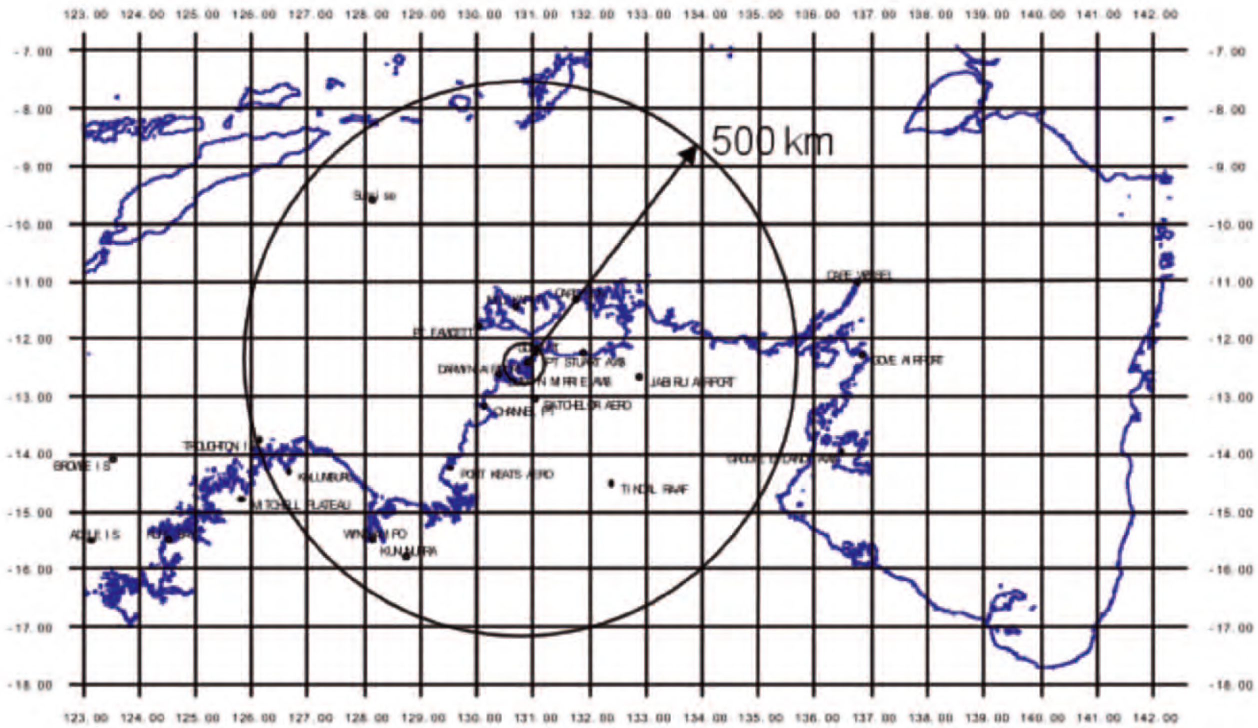

Figure 6: Assumed region of influence of tropical cyclones.

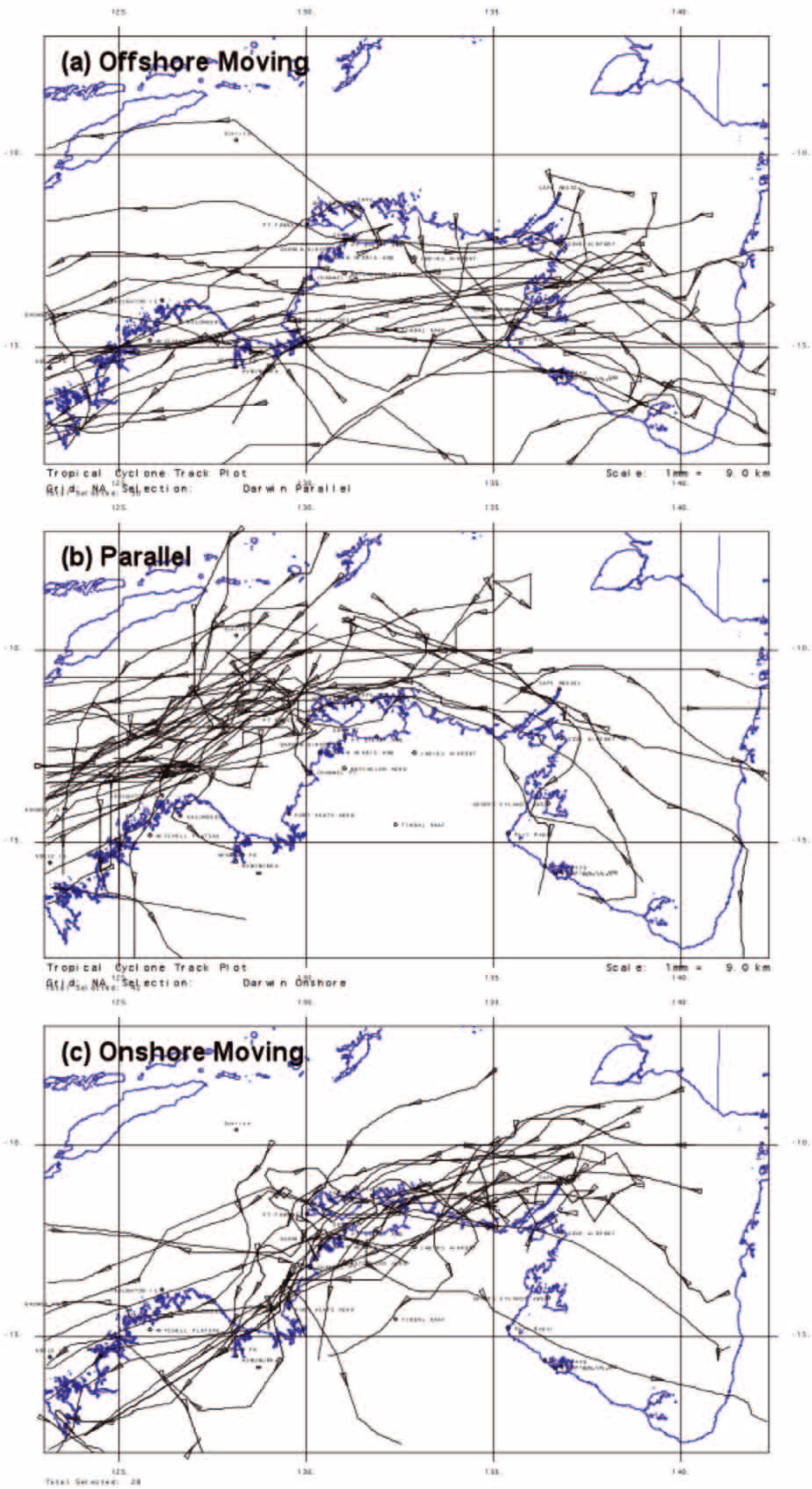

Figure 7: Assessed historical tropical cyclone track classes.

Each of the 100 historical storms is allocated to one of three climatological classes: offshore moving, parallel to the coast or onshore moving (refer Figure 7) and the statistical distributions of intensity, speed and size have been assessed on that basis. The onshore moving storm class is the most significant in terms of generating storm tide in the Kakadu area. The model does not consider non-tropical cyclone events such as strong monsoons, which can also generate prolonged but typically small (< 0.5 m) storm surge events.

The peak intensity distribution under present climate conditions for each track class has then been based on an Extreme Value Analysis of estimated central pressures. The individual track analyses are combined and summarised in Figure 8 (solid line), where the Maximum Potential Intensity (MPI) is estimated to be 880 hPa, based on the regional thermodynamic potential (e.g. Tonkin et al. 2000). The MPI is the intensity to which a tropical cyclone is expected to increase towards if there are no inhibiting mechanisms (vertical shear, intrusion of dry air, landfall) and the energy available from the ocean (ocean heat content) is able to be optimised. It is rare for tropical cyclones to attain their MPI, especially in this region where the ocean expanse is somewhat limited by surrounding islands and prominent peninsulas.

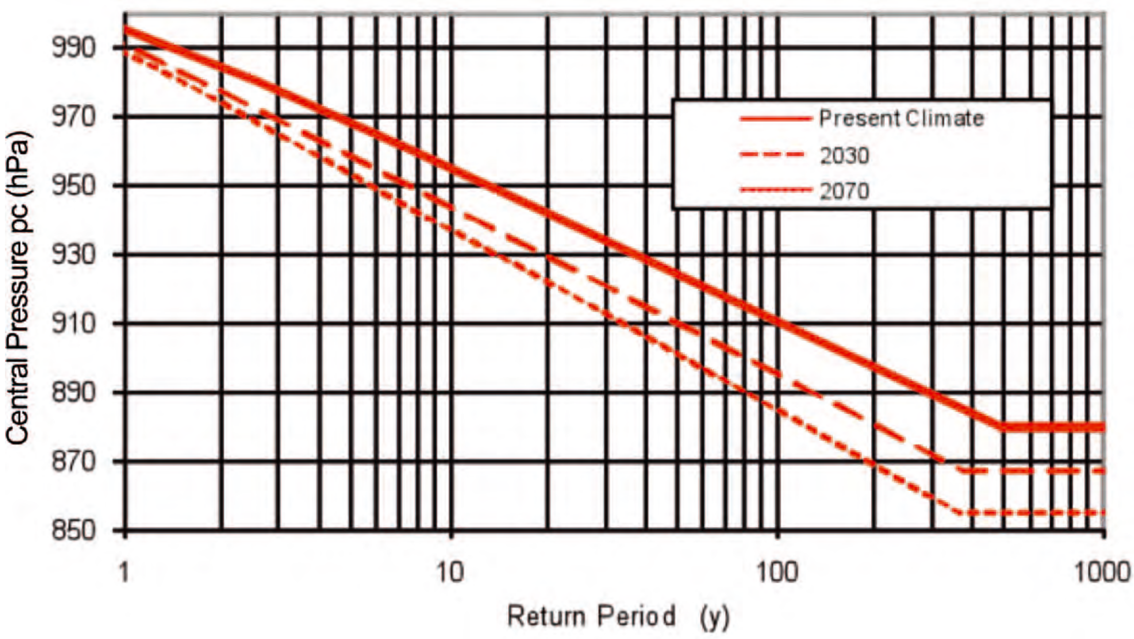

Figure 8: Assumed tropical cyclone intensity distribution within 500 km radius of Darwin.

Potential Enhanced-Greenhouse Climate Change

In addition to the “present” climate, Figure 8 shows estimated effects of potential Enhanced-Greenhouse climate change, based on the scenario assumptions in Table 1 below, which have been agreed with BMT WBM Pty Ltd:

Table 1 : Adopted Enhanced-Greenhouse Scenarios

YEAR	2030	2070
Scenarios:		
MSL Increase (m)	0.14	0.70
MPI Increase	10%	20%
Frequency Increase	0%	10%

The sensitivity of the regional risk of storm tide under Enhanced-Greenhouse conditions is assessed through the use of two specific future scenarios that may modify the mean sea level (MSL), the maximum intensity of tropical cyclones (MPI) and the frequency of tropical cyclones by the year 2030 and 2070. The components of each scenario have been based on a variety of sources as described below.

Potential Changes in Mean Sea Level (MSL)

The principal reference in this regard is IPCC (2007), also known as "Assessment Report 4" or "AR4", together with CSIRO (2007), which repeats the AR4 projections of future sea level increases and provides some comment on Australian sea levels in particular. In this case the adopted MSL rise scenarios of 0.14 m by 2030 and 0.70 m by 2070 have been specified by the client.

Potential changes in Tropical Cyclone Intensity

Although IPCC (2007) does address aspects of future tropical cyclone climatology, this area of research is advancing rapidly and the preferred reference is WMO (2006), which summarised the status of current research in this area after the publication close-off date for the IPCC AR4 update. It was concluded that there is an agreed likely increase in the Maximum Potential Intensity (MPI) of tropical cyclones as the mean global temperature rises of about 3 to 5% per degree Celsius. Assuming a 2 to 4 degree range is possible, this may lead to an upper level increase of as much as 20% by (say) 2070. Based on the above, conservative tropical cyclone intensity increases have been used, as detailed in Table 1.

Potential changes in Tropical Cyclone Frequency and Track

WMO (2006) reports that the consensus from many advanced modelling studies is actually for a potential reduction in the global number of tropical cyclones, although regional differences can be high. Regarding tracks, the most likely change might be a slight poleward movement in some regions. For tropical regions like Kakadu, it is not expected that there would be any specific change in storm tracks under future climate scenarios. However, as shown in Table 1, a nominal 10% increase in frequency has been assumed by the year 2070.

Probabilistic Storm Tide Estimates

The simulation model was then set to generate 50,000 years of synthetic tropical cyclone events, to estimate the storm surge, wave setup and runup components over a 36 hour period for each storm, and superimpose these on the generated astronomical tides at a resolution of 30 minutes. The wave setup and runup are made sensitive to the local water depth and a nominal allowance is included for non-linear surge and tide interaction of ±10%, whereby the peak surge is reduced when it occurs at a high tide, and increased when it occurs at a low tide. The wave setup component is clipped by the actual land level that, based on the available data, is close to HAT. Likewise, wave runup is also clipped to this level. The combined statistics of the total water levels are then analysed to determine the return periods of total water level exceedance.

Figure 9 shows a selection of the modelled storm tide components for "present" climate. The solid black line is the surge magnitude, which is statistically combined with the tide, whose peak magnitude is indicated by the HAT limit. The sites at the river mouths additionally indicate the incident significant wave height and potential wave setup magnitude. However, because these are not acting on a beachfront, they are deemed not effective in raising the local water levels, as seen by the overlaid total storm tide (tide+surge+setup), tide+surge and total wave runup curves.

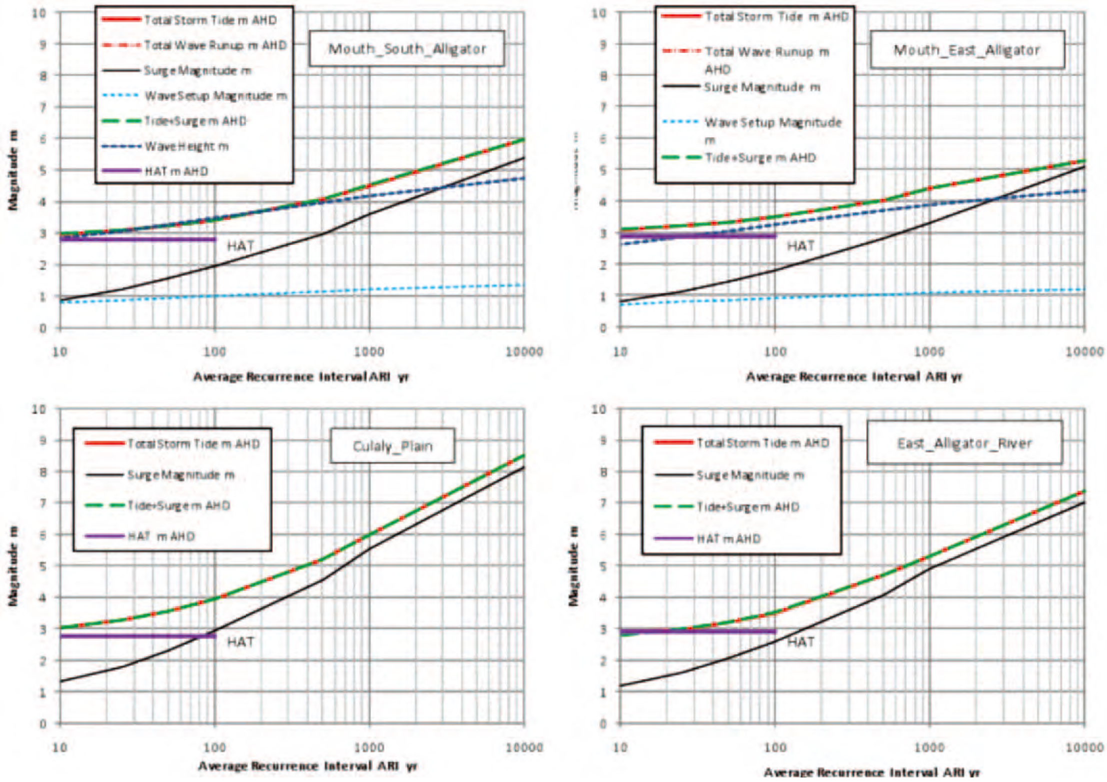

Figure 9: Selection of modelled storm tide component levels for "Present" climate.

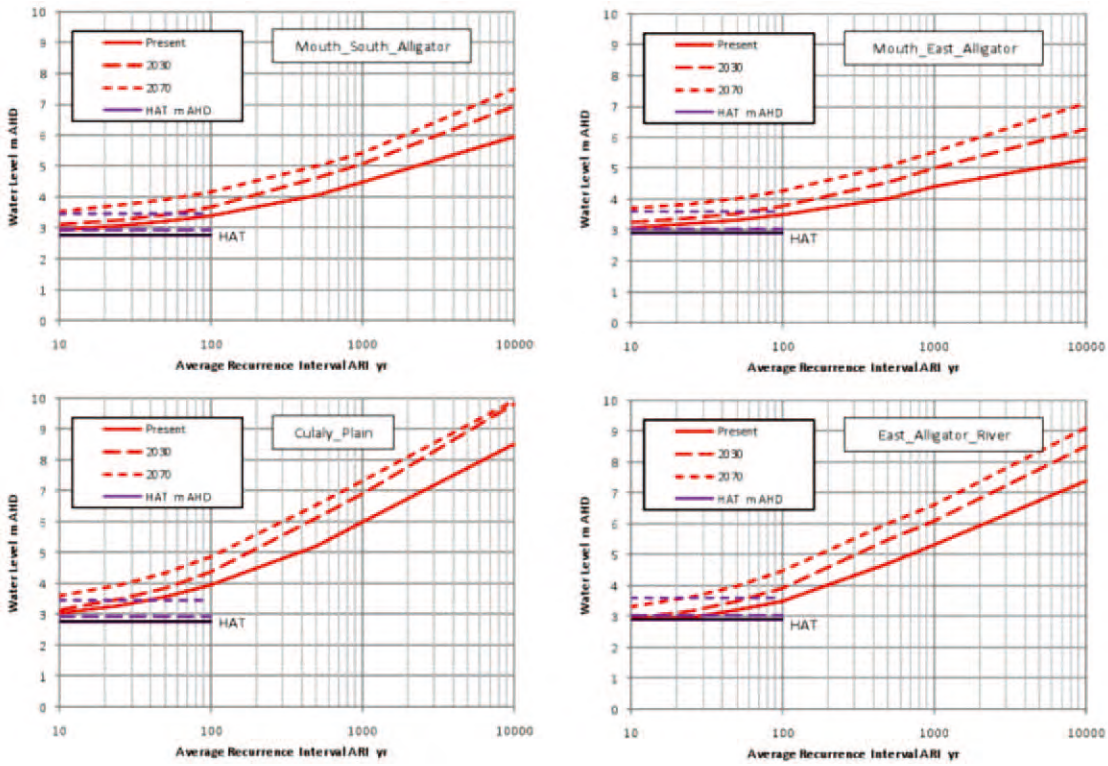

Figure 10: Summary of modelled total storm tide levels for the climate scenarios.

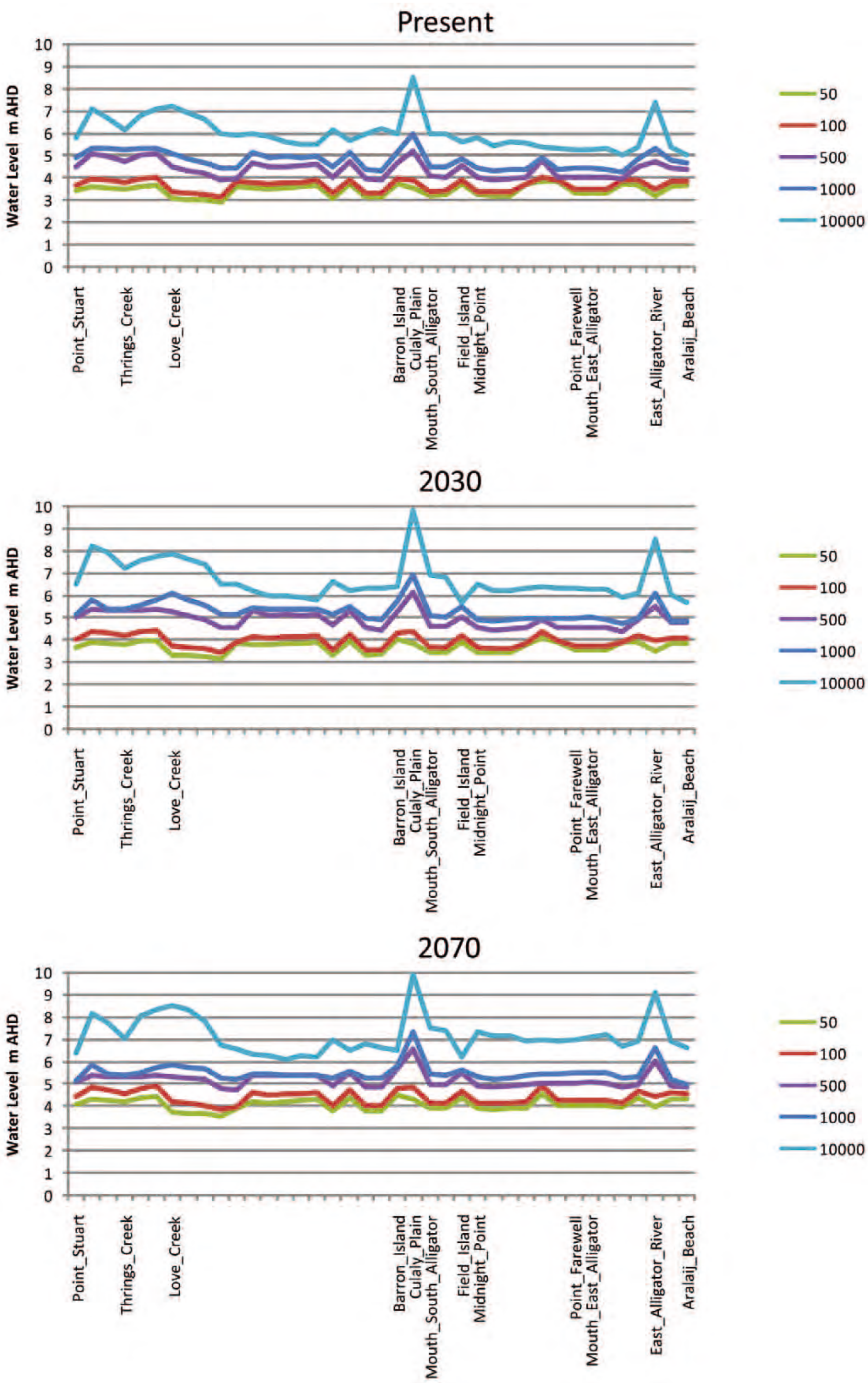

Figure 11: Summary of modelled ARI of total storm tide levels across the Kakadu coastal margin for the various climate scenarios.

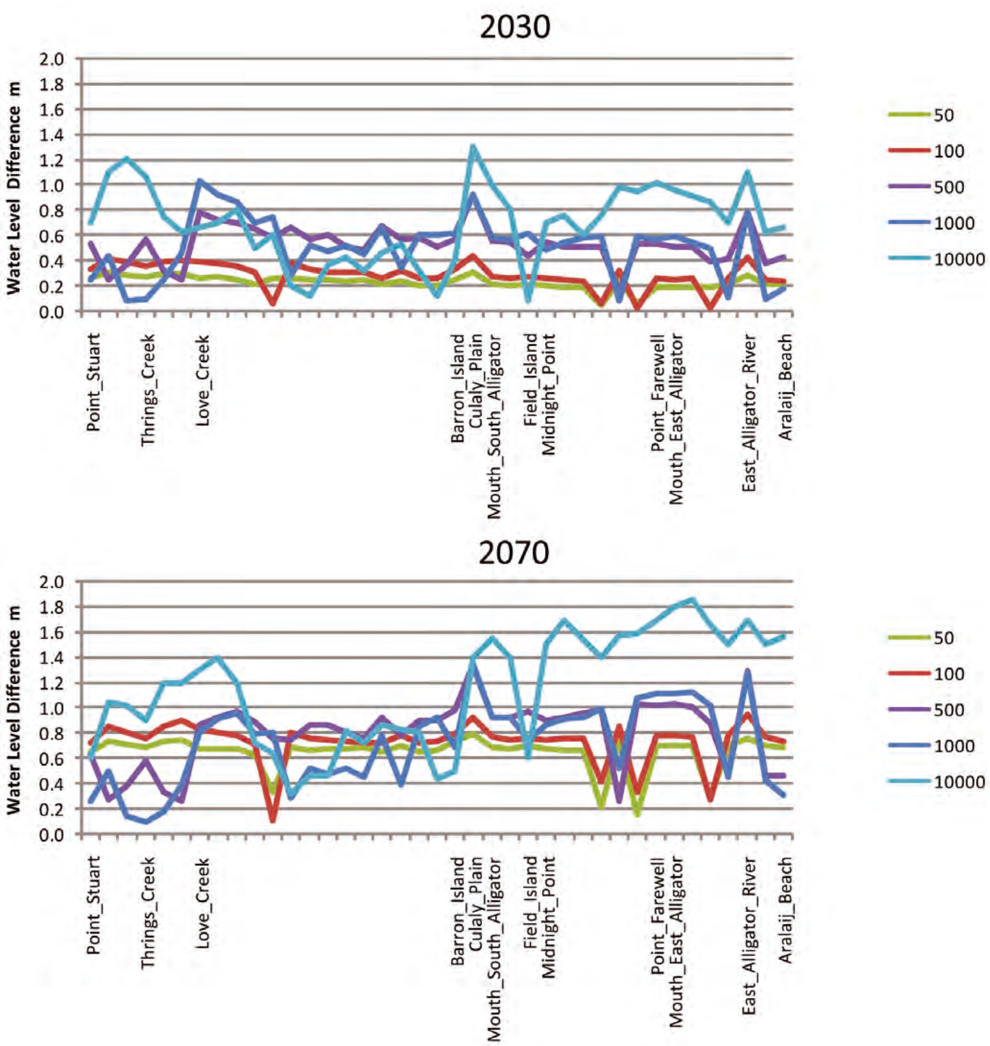

Figure 12: Summary of differences of modelled total storm tide levels relative to present climate across the Kakadu coastal margin for the Enhanced-Greenhouse climate scenarios.

Figure 10 then summarises the effect of each future climate scenario, which can be seen to increase the risks due to the combined effects of sea level rise, cyclone intensity and frequency of occurrence assumptions.

Figure 11 shows the variation in total storm tide level estimates across the Kakadu coastal margin from west to east (refer Figure 4). The two highest levels in each case are the up-river sites in South Alligator (Culaly_Plain) and in East Alligator. The contribution made by wave setup to these totals varies in response to the model assumption regarding dune crest levels, but is typically small or zero. Figure 12 simply re-presents the Figure 11 results as differences relative to present climate estimates.

The estimated total storm tide levels at all Kakadu costal margin sites for a range of average recurrence intervals are then summarised in Table 3.

A series of representative 100 yr ARI tide+surge and surge-only hydrographs at Site 155 (Mouth_South_Alligator) have been supplied separately to facilitate BMT WBM river modelling.

Conclusions

This estimate of statistical storm tide levels along the Kakadu National Park coastal margins has been based on constructing a statistical model of the regional tropical cyclone climatology, combined with storm tide estimates from a parametric model and generating astronomical tides over a simulation period of 50,000 years. The model considers three climate scenarios: present, year 2030 and year 2070. The MSL-rise scenarios have been based on client supplied levels. The future tropical cyclone climate scenarios are based on contemporary research consensus. Although not presented here, the statistical model correctly reproduces the expected regional HAT levels in a statistical context and also generates mean and gust wind speeds that are conservative relative to the long term measurements available from Darwin Airport (40-50 years).

Table 3: Summary of Total Storm Tide Predictions (m AHD)

			ARI (YR)	PRESENT CLIMATE						YEAR 2030						YEAR 2070					
				HAT	50	100	500	1000	10000	HAT	50	100	500	1000	10000	HAT	50	100	500	1000	10000
SITE	ID	LAT	LON	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
		°AGD84	°ADG84	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD
Point_Stuart	107	-12.2119	131.8970	2.24	3.4	3.7	4.5	4.9	5.8	2.38	3.7	4.0	5.0	5.1	6.5	2.94	4.1	4.4	5.1	5.1	6.4
	108	-12.2738	131.9470	2.30	3.6	4.0	5.1	5.3	7.1	2.45	3.9	4.4	5.4	5.8	8.2	3.00	4.4	4.8	5.4	5.8	8.1
	109	-12.2503	131.9390	2.30	3.6	3.9	5.0	5.3	6.7	2.44	3.9	4.3	5.3	5.4	7.9	3.00	4.3	4.7	5.3	5.5	7.7
Thrings_Creek	110	-12.2268	131.9300	2.28	3.5	3.8	4.7	5.3	6.1	2.42	3.8	4.2	5.3	5.4	7.2	2.98	4.2	4.6	5.3	5.4	7.0
	111	-12.2653	131.9710	2.31	3.6	4.0	5.0	5.3	6.8	2.46	3.9	4.4	5.3	5.6	7.5	3.01	4.4	4.8	5.4	5.5	8.0
	112	-12.2802	132.0040	2.34	3.7	4.0	5.1	5.3	7.1	2.48	4.0	4.4	5.4	5.8	7.7	3.04	4.4	4.9	5.4	5.7	8.3
Love_Creek	113	-12.2951	132.0370	2.35	3.1	3.4	4.5	5.1	7.2	2.50	3.3	3.8	5.3	6.1	7.9	3.05	3.7	4.2	5.4	5.9	8.5
	114	-12.2866	132.0610	2.36	3.0	3.3	4.4	4.9	6.9	2.50	3.3	3.7	5.1	5.8	7.6	3.06	3.7	4.1	5.3	5.8	8.3
	115	-12.2780	132.0850	2.38	3.0	3.3	4.2	4.7	6.6	2.53	3.3	3.6	4.9	5.6	7.4	3.08	3.7	4.0	5.2	5.7	7.8
	116	-12.2460	132.1000	2.38	2.9	3.1	3.9	4.4	6.0	2.53	3.1	3.4	4.6	5.1	6.5	3.08	3.5	3.8	4.8	5.2	6.7
	119	-12.2374	132.1240	2.38	3.6	3.9	4.0	4.4	5.9	2.53	3.9	3.9	4.6	5.2	6.5	3.08	3.9	4.0	4.7	5.2	6.5
	122	-12.2289	132.1480	2.39	3.5	3.8	4.7	5.2	6.0	2.53	3.8	4.2	5.3	5.4	6.2	3.09	4.2	4.6	5.4	5.4	6.3
	125	-12.1968	132.1640	2.41	3.5	3.7	4.5	4.9	5.8	2.56	3.8	4.1	5.1	5.4	6.0	3.11	4.2	4.5	5.4	5.4	6.3
	128	-12.1882	132.1880	2.48	3.6	3.8	4.5	4.9	5.6	2.62	3.8	4.1	5.1	5.4	6.0	3.18	4.2	4.6	5.4	5.4	6.1
	130	-12.1797	132.2120	2.51	3.6	3.8	4.6	4.9	5.5	2.65	3.8	4.1	5.1	5.4	5.9	3.21	4.3	4.6	5.4	5.4	6.3
	135	-12.1711	132.2360	2.54	3.7	3.9	4.6	5.0	5.5	2.69	3.9	4.2	5.1	5.4	5.8	3.24	4.4	4.6	5.4	5.4	6.2
	138	-12.2095	132.2770	2.64	3.1	3.3	4.0	4.5	6.1	2.78	3.3	3.6	4.7	5.2	6.6	3.34	3.8	4.0	4.9	5.3	7.0
	139	-12.1860	132.2680	2.62	3.7	4.0	4.7	5.2	5.7	2.76	4.0	4.3	5.3	5.5	6.2	3.32	4.4	4.7	5.5	5.6	6.5
	143	-12.2009	132.3010	2.67	3.1	3.3	4.0	4.4	6.0	2.81	3.3	3.6	4.5	5.0	6.3	3.37	3.8	4.0	4.9	5.3	6.8
	146	-12.1923	132.3250	2.70	3.1	3.3	3.9	4.3	6.2	2.84	3.3	3.6	4.4	4.9	6.3	3.40	3.8	4.0	4.8	5.2	6.6
Barron_Island	152	-12.1838	132.3490	2.76	3.8	4.0	4.7	5.1	6.0	2.90	4.0	4.3	5.3	5.8	6.4	3.46	4.5	4.8	5.7	5.8	6.5
Culaly_Plain	154	-12.3160	132.4260	2.78	3.6	3.9	5.2	6.0	8.5	2.92	3.9	4.4	6.1	6.9	9.8	3.48	4.3	4.9	6.6	7.3	9.9
Mouth_South_ Alligator	155	-12.1752	132.3730	2.78	3.2	3.4	4.1	4.5	6.0	2.92	3.4	3.7	4.6	5.1	6.9	3.48	3.9	4.2	5.0	5.4	7.5
	160	-12.1666	132.3970	2.80	3.2	3.4	4.0	4.5	6.0	2.95	3.4	3.7	4.6	5.1	6.8	3.50	3.9	4.2	5.0	5.4	7.4
Field_Island	161	-12.0727	132.3620	2.68	3.7	3.9	4.6	4.9	5.6	2.82	3.9	4.2	5.0	5.5	5.7	3.38	4.4	4.7	5.5	5.6	6.2
Midnight_Point	163	-12.1580	132.4210	2.81	3.2	3.4	4.0	4.4	5.8	2.96	3.4	3.7	4.5	4.9	6.5	3.51	3.9	4.2	4.9	5.3	7.3
	165	-12.1259	132.4370	2.80	3.2	3.4	3.9	4.3	5.5	2.94	3.4	3.6	4.4	4.9	6.2	3.50	3.9	4.1	4.8	5.2	7.2

			ARI (YR)	PRESENT CLIMATE						YEAR 2030						YEAR 2070					
				HAT	50	100	500	1000	10000	HAT	50	100	500	1000	10000	HAT	50	100	500	1000	10000
SITE	ID	LAT	LON	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
		°AGD84	°ADG84	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD	AHD
	167	-12.1173	132.4610	2.81	3.2	3.4	4.0	4.3	5.6	2.95	3.4	3.6	4.5	4.9	6.2	3.51	3.9	4.1	4.9	5.3	7.1
	169	-12.1087	132.4850	2.83	3.7	3.8	4.0	4.4	5.5	2.97	3.8	3.8	4.5	5.0	6.3	3.53	3.9	4.2	5.0	5.4	6.9
	172	-12.1002	132.5090	2.87	3.8	4.1	4.8	4.9	5.4	3.01	4.1	4.4	4.9	5.0	6.4	3.57	4.6	4.9	5.0	5.4	7.0
	176	-12.0916	132.5330	2.88	3.9	3.9	4.0	4.4	5.4	3.02	3.9	3.9	4.6	5.0	6.3	3.58	4.0	4.3	5.1	5.5	6.9
Point_Farewell	179	-12.0830	132.5570	2.90	3.3	3.5	4.0	4.4	5.3	3.04	3.5	3.7	4.6	5.0	6.3	3.60	4.0	4.3	5.1	5.5	7.0
Mouth_East_ Alligator	181	-12.0744	132.5810	2.91	3.3	3.5	4.0	4.4	5.3	3.05	3.5	3.8	4.6	5.0	6.3	3.61	4.0	4.3	5.1	5.5	7.1
	183	-12.0657	132.6050	2.90	3.3	3.5	4.0	4.4	5.3	3.04	3.5	3.8	4.6	4.9	6.3	3.60	4.0	4.3	5.1	5.5	7.2
	184	-12.0423	132.5960	2.89	3.7	3.9	4.0	4.2	5.0	3.03	3.9	3.9	4.4	4.7	5.9	3.59	4.0	4.2	4.9	5.3	6.7
	186	-12.0102	132.6110	2.88	3.7	3.9	4.5	4.9	5.4	3.02	3.9	4.2	4.9	5.0	6.1	3.58	4.4	4.7	5.0	5.3	6.9
East_Alligator_ River	191	-12.1424	132.6880	2.91	3.2	3.5	4.7	5.3	7.4	3.05	3.5	3.9	5.5	6.1	8.5	3.61	4.0	4.5	6.0	6.6	9.1
	192	-11.9781	132.6260	2.84	3.6	3.8	4.4	4.8	5.4	2.98	3.9	4.1	4.8	4.9	6.0	3.54	4.3	4.6	4.9	5.2	6.9
Aralaij_Beach	193	-11.9546	132.6170	2.83	3.7	3.8	4.4	4.7	5.0	2.98	3.9	4.1	4.8	4.8	5.7	3.53	4.3	4.6	4.8	5.0	6.6

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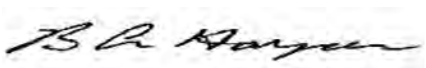

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Appendix K: Tidal Channel and Adjacent Floodplain Model

SAR River and Floodplain Hydrodynamic Model

Introduction

The SAR floodplain, including the main river channel, between Yellow Water and the coast is the conduit through which the annual freshwater flows, which can be in excess of 3,600 gigalitres per year (or more than seven times the volume of Sydney Harbour), are drained from the catchment. The floodplain is extremely flat with falls of only 1–2 metres in over 100km and the depressions left by historic channel alignments and settlement of previous marine deposits are filled with freshwater during the wet and evaporate during the dry. This retention of freshwater in billabongs, paleo-channels and other features is the key factor in maintaining the ecological diversity of the region and its attraction to traditional owners and more recently tourists.

The SAR river and floodplain hydrodynamic model has been developed to incorporate the existing tidal and storm surge water level boundary conditions at the coast and freshwater runoff flows at the tidal interface. These boundary conditions can be changed to reflect the predicted climate change scenarios and the model then used to simulate the impacts.

River and Floodplain Hydrodynamic Model

The SAR river and floodplain model has been developed using the in-house finite volume model TUFLOW-FV. A finite volume model is well suited to the SAR because it is very robust in its handling of wetting and drying, i.e. when water first covers a dry cell (land) and then when water later leaves the cell. This is a feature common to most model cells on the floodplain. Also, and the flexible mesh allows areas of interest i.e. the tidal interface, to have higher resolution while other areas of less interest (high ground) while still maintaining computational efficiency than a finite difference model. As the SAR operates mainly as a tidal channel in the dry and then a larger slow draining floodplain in the wet, both these features improve the model performance. Currently the mesh for the model contains over 13,000 nodes and 18,000 cells and is able to run one full year of flows in about 24 hours. The mesh representing the tidal channel and floodplain downstream from Cooinda is shown in Figure 1.

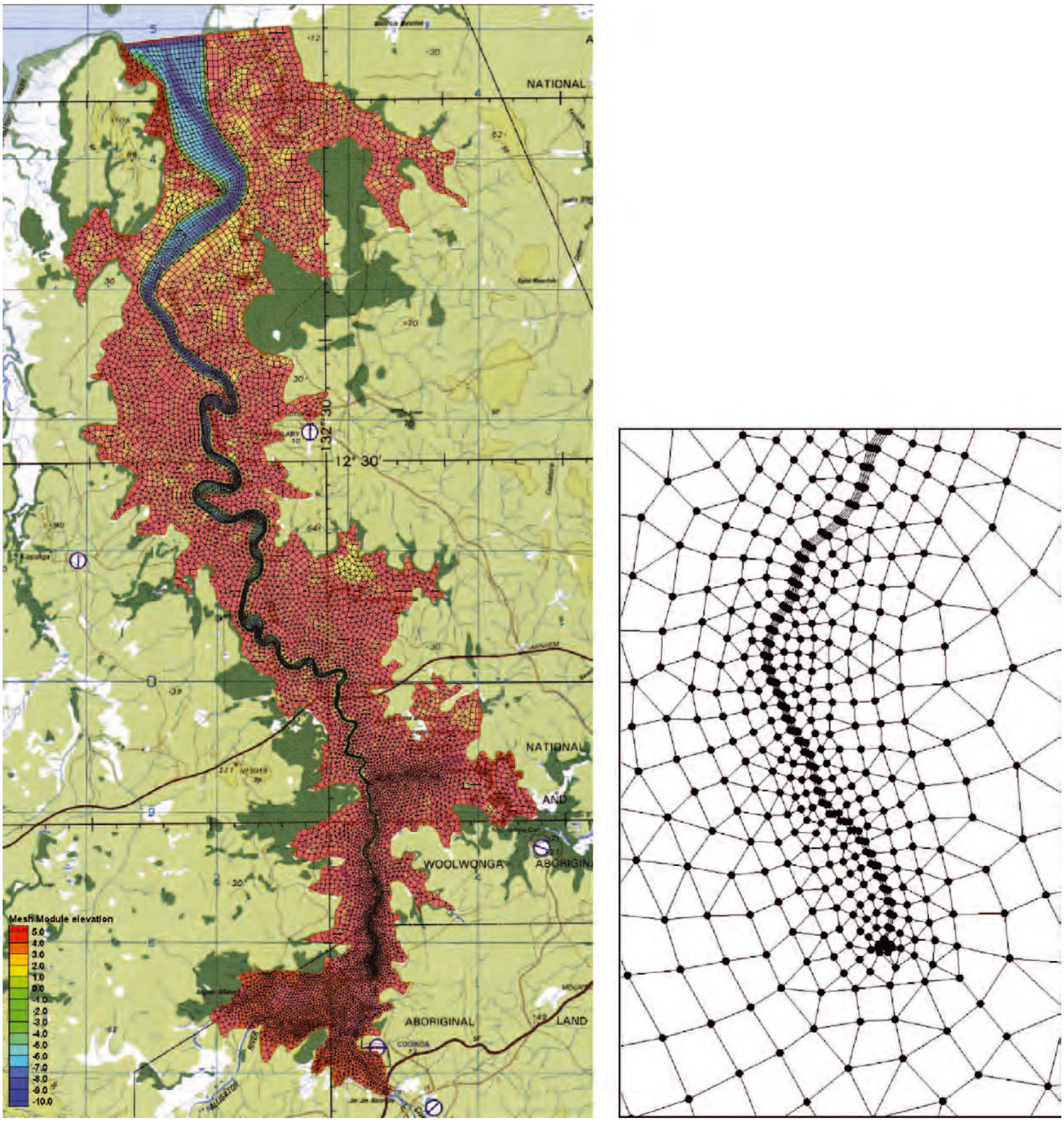

Figure 1: South Alligator River and floodplain hydrodynamic model mesh.

River Model and Calibration

Towards the end of the dry, when there is no freshwater runoff from the catchment, the river acts as a saltwater tidal channel with little interaction with the floodplain although myriad dendritic channels exist and some of the natural levees are scoured (refer Section 3.2.5). The tidal channel component of the model was developed from 25 cross sections surveyed by Dave Williams (previously NRETA now AIMS) in late 2008. At this time he also installed four tide gauges for about one month (see Figure 2 for locations) and carried out ADCP flow profiles. The tidal channel component of the model was calibrated to this recorded data (refer Figures 3 to 5).

Figure 2: Locations of tide gauges.

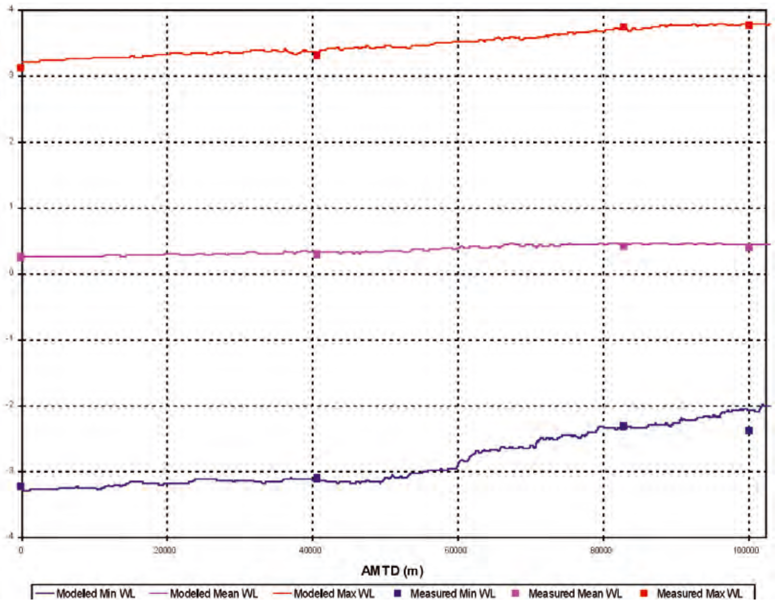

Figure 3: Measured and modelled river water levels.

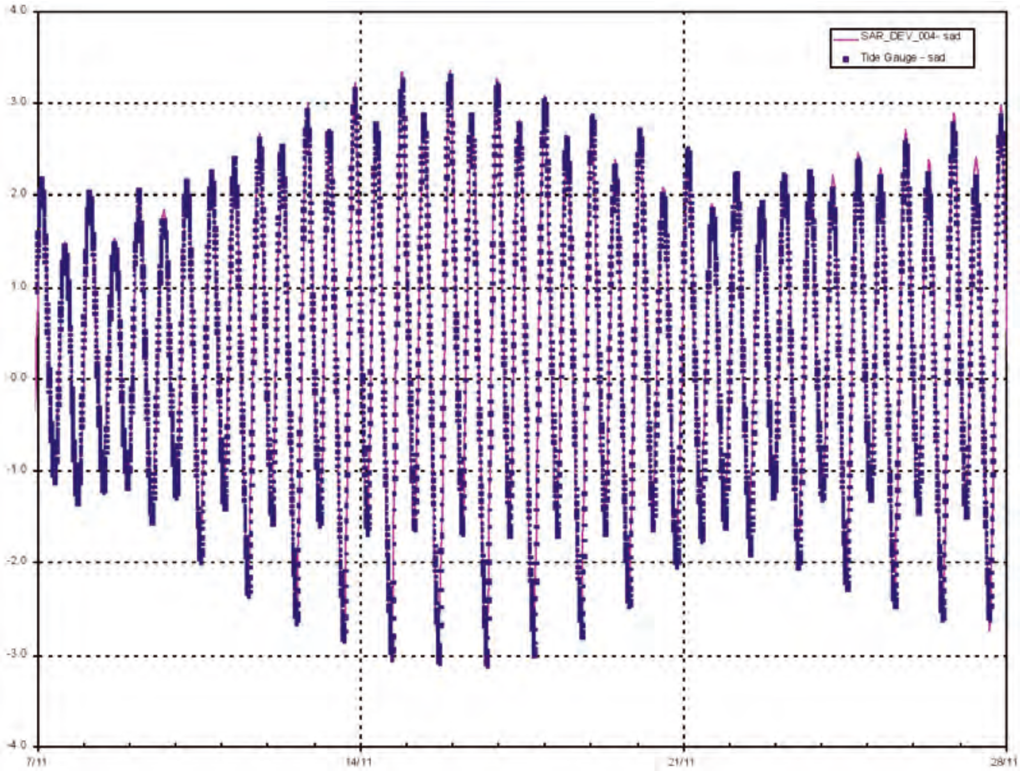

Figure 4: Typical river model level calibration plot.

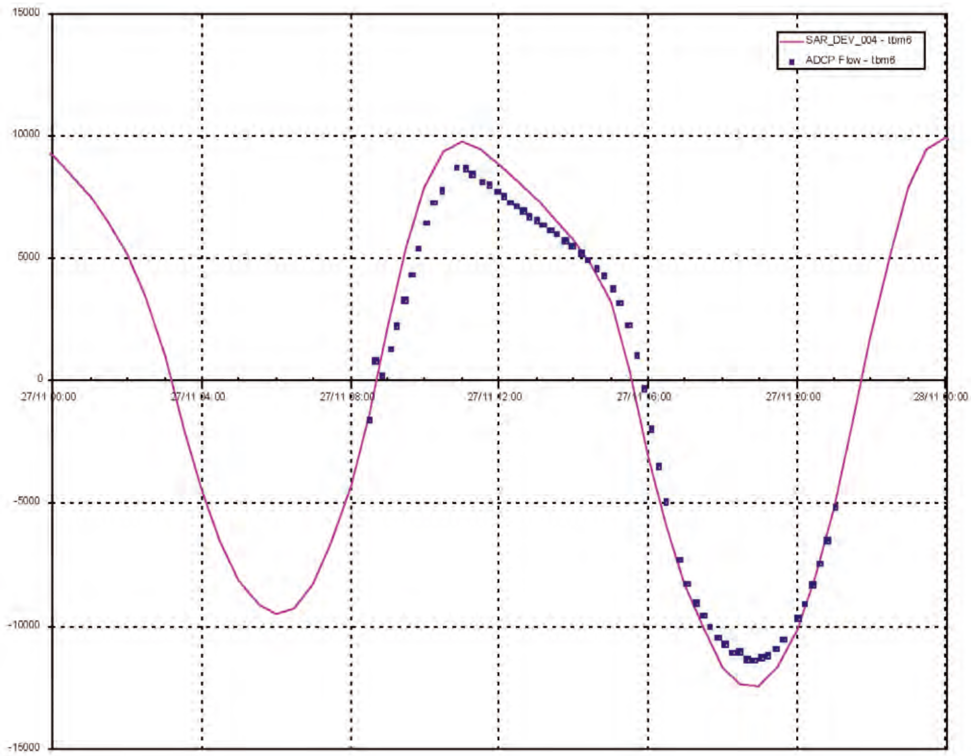

Figure 5: Typical river model flow calibration plot.

Floodplain Model

Initially, it was hoped to establish levels for the floodplain from an SRTM dataset (flown in 2000) which had been interpreted and improved by Geoscience Australia. However, the final DEM which was received in December 2008 still included vegetation and had a stated vertical accuracy of +/-3-5m with levels given in increments of 1m. Due to the lack of alternative data sources a mean level for the floodplain level was interpreted from the SRTM DEM and other information including aerial photographs and published papers. This interpreted level was about RL 5m. A sensitivity analysis was also carried out with a level around 1.5m lower which is the level reported by Vertessy and others. It is hoped that the collection of LiDAR data in the future will rectify the lack of appropriate data for the floodplain. The levees along the SAR were interpreted at RL 3.75 on the basis of the published information that the levees are overtopped by occasional peak spring tides.

Boundary Conditions

The downstream boundary of the model is driven by the tidal levels recorded in 2008 and extended with reference to the Darwin tide gauge. The future impact scenarios will include SLR and storm surge changes added to this boundary. SLR conditions adopted for the model are SLR in 2030 +143mm and SLR for 2070 +700mm and a portion of the tidal and future SLR tidal boundary level data is shown in Figure 6 below.

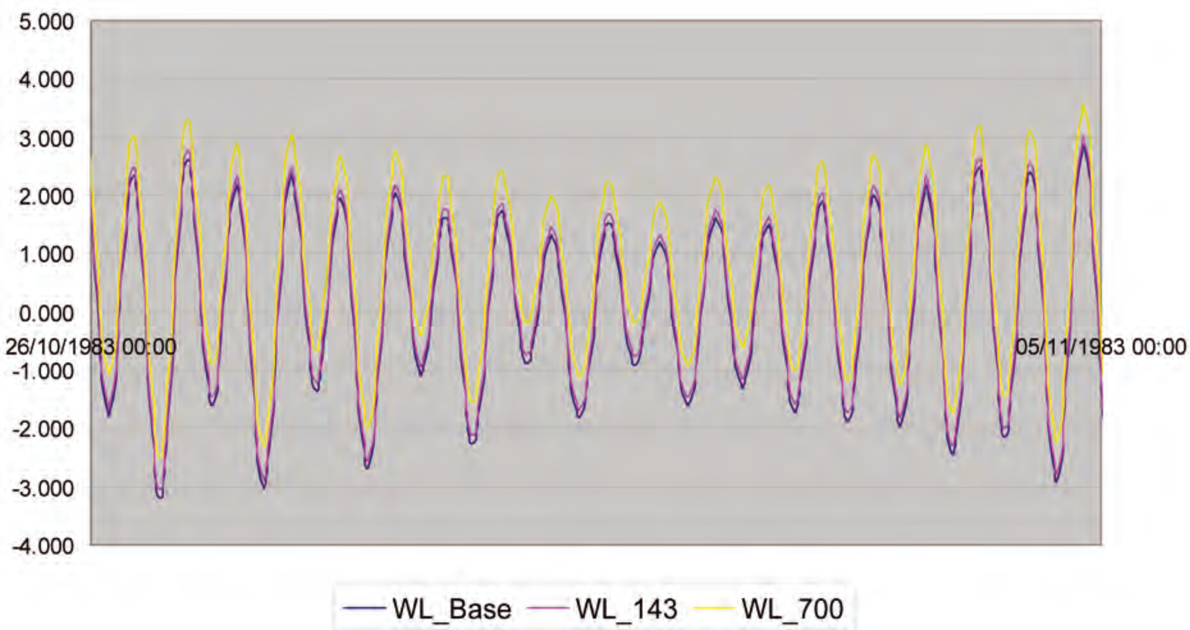

Figure 6: Typical river model tidal boundary levels.

In addition to sea level rise it is expected that about one cyclone will occur in each season. The report on the impact of climate change on the surge relating from these cyclones is given in the report from SEA (Dr Bruce Harper) in Appendix J. The report concludes that the likely increase in storm tide in 2030 will be 150m in addition to the SLR of 143mm and for 2070 and extra 100mm in addition to the SLR of 700mm. These levels were included at an appropriate time in the model boundary time series.

The upstream boundary conditions are flows related to rainfall changes as detailed in the SAR Catchment Modelling in Appendix I. These flow inputs at Jim Jim Creek, South Alligator River and Nourlangie Creek were introduced as a time series into in the floodplain as shown in Figure 7 below.

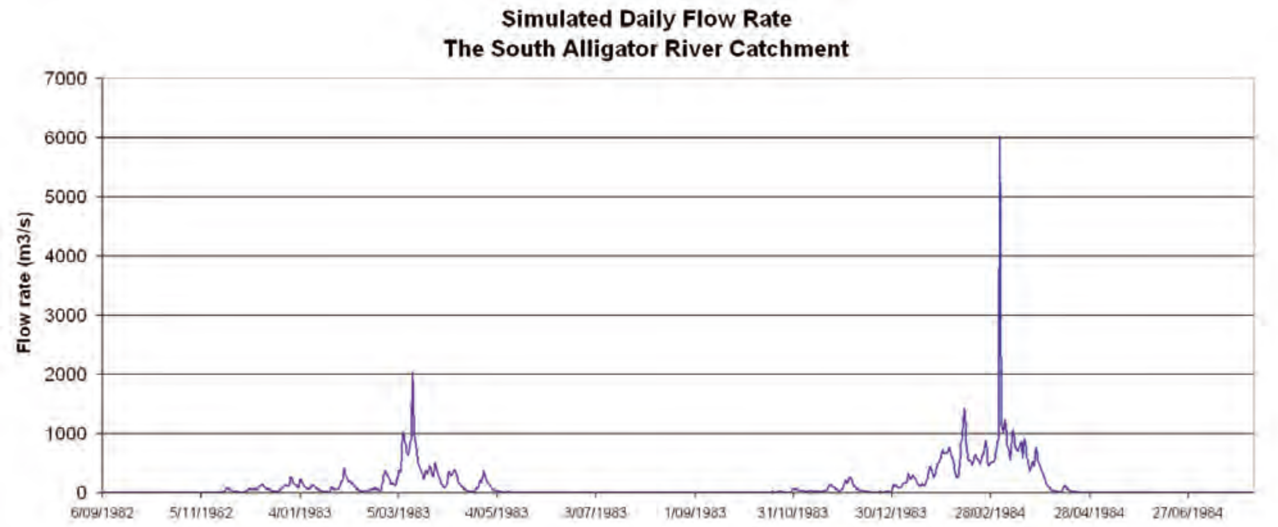

Figure 7: Typical catchment flow time series for input to floodplain model.

Model Results

The river and floodplain hydrodynamic model was run in two separate modes to isolate the typical dry and wet conditions as indicated below:

- With tidal boundaries and no fresh inflow to simulate conditions in the dry and estimate the change to levee overtopping with SLR; and
- With tidal boundaries and catchment input to simulate conditions during the wet and impacts on floodplain inundation and salinity in the channel.

The existing and SLR scenarios were run on the tide only model to establish the hydraulic efficiency of the estuary and the likely increase in overtopping of the levees. Figure 8 clearly shows that the tide (and storm surge) is able to propagate very efficiently up the SAR and the loss in high tide level after about 80km is related to increasing water loss over the levee rather that energy loss due to bottom friction. Figure 9 shows the increase in level and duration of the flow over the levee at 107km under the extreme case (700mm SLR). Figures 10 and 11 are screenshots from the included animation of model results for the existing and 700mm SLR cases.

Little reliable information is able to be extracted from the model on flows on the floodplain for the existing and future cases because of the poor resolution of the level data and the lack of sediment data.

When the floodplain model is run for a typical year of existing wet and dry conditions it is able to replicate the flushing of saltwater from the system down to about 25km from the mouth as reported by Vertessy. Figure 12 is a screenshot from the included animation of model results for the salinity case where salinity is reduced through most of the estuary.

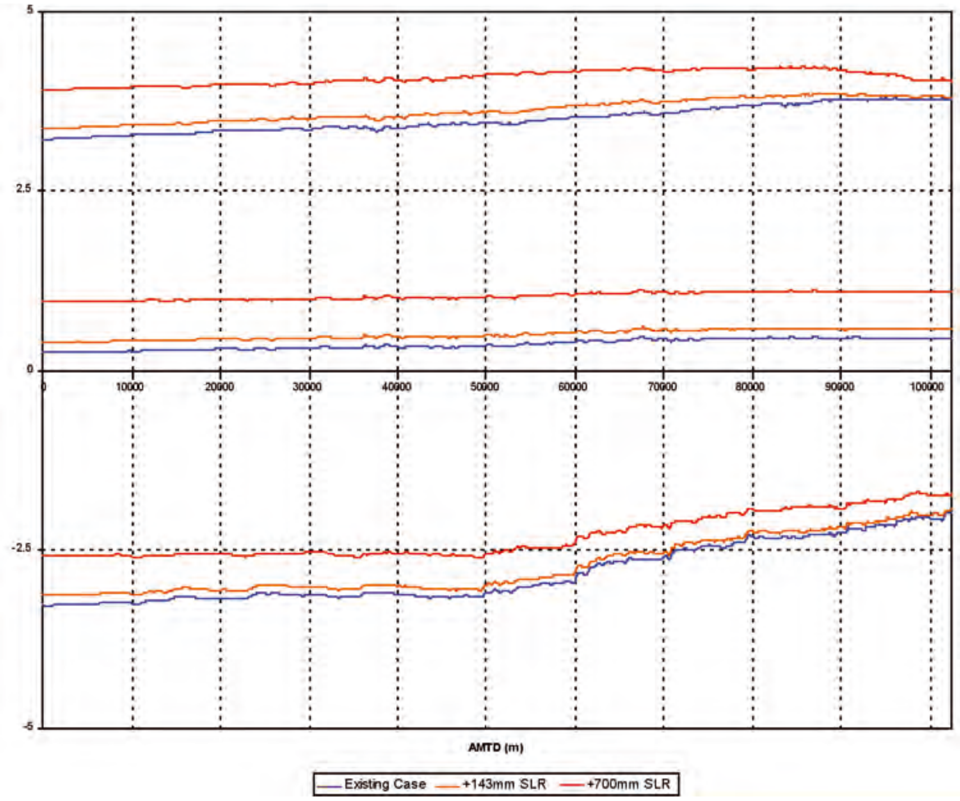

Figure 8: Water levels (min,mean,max) for existing case and 700mm SLR.

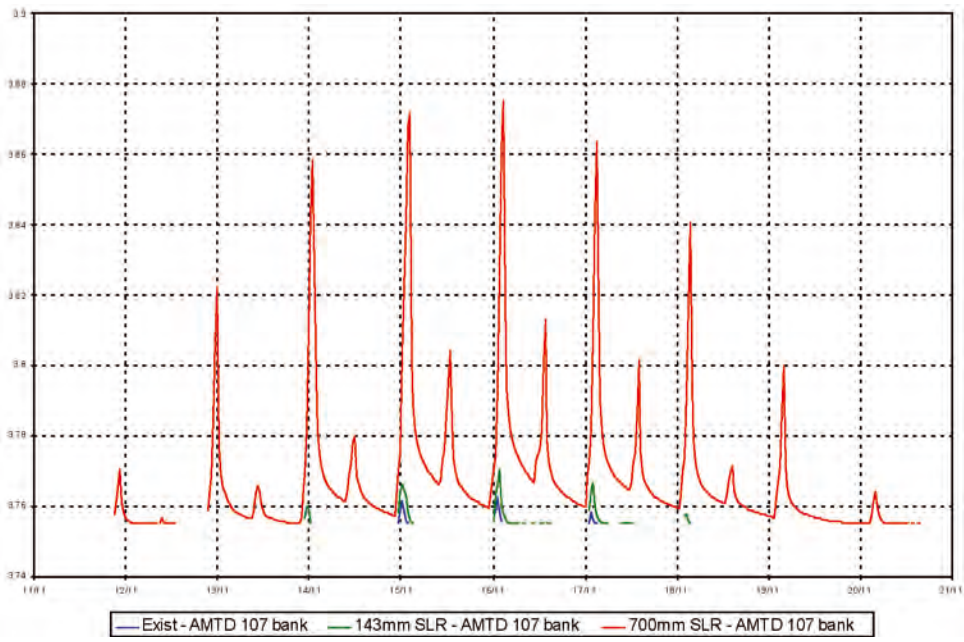

Figure 9: Water levels overtopping levees for existing case and SLR scenarios.

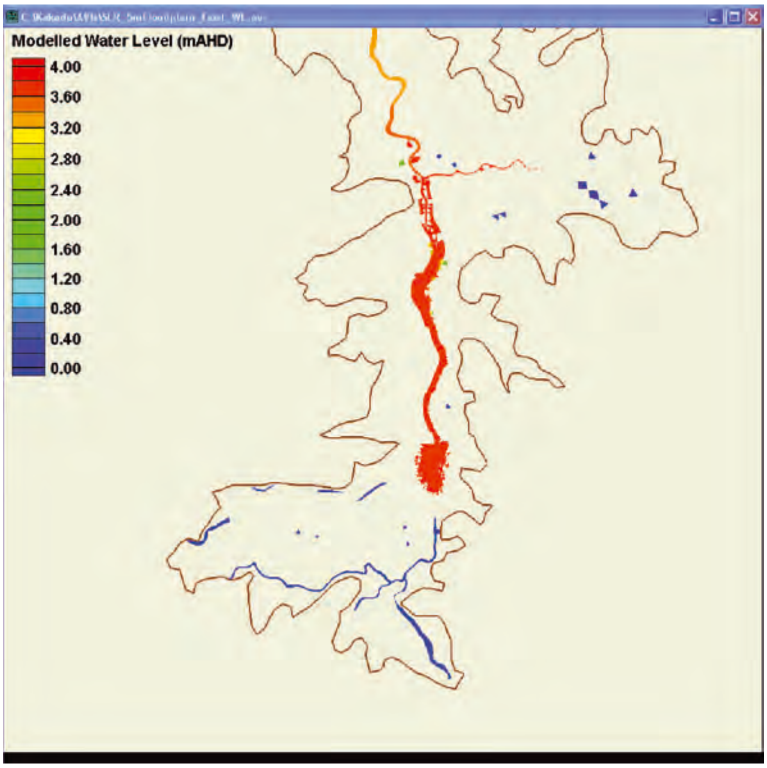

Figure 10: Water overtopping levees for existing case

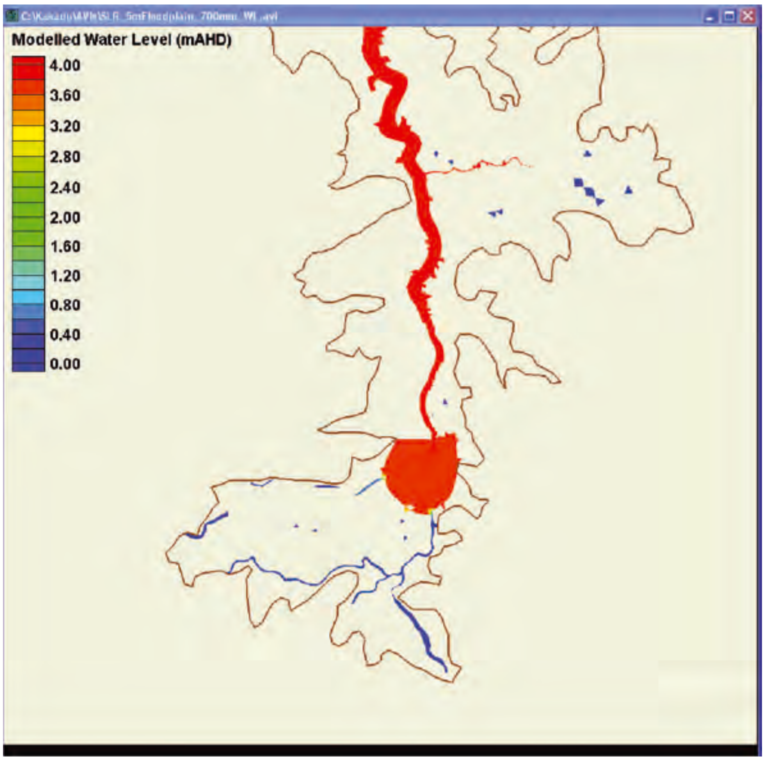

Figure 11: Water overtopping levees for 700mm SLR

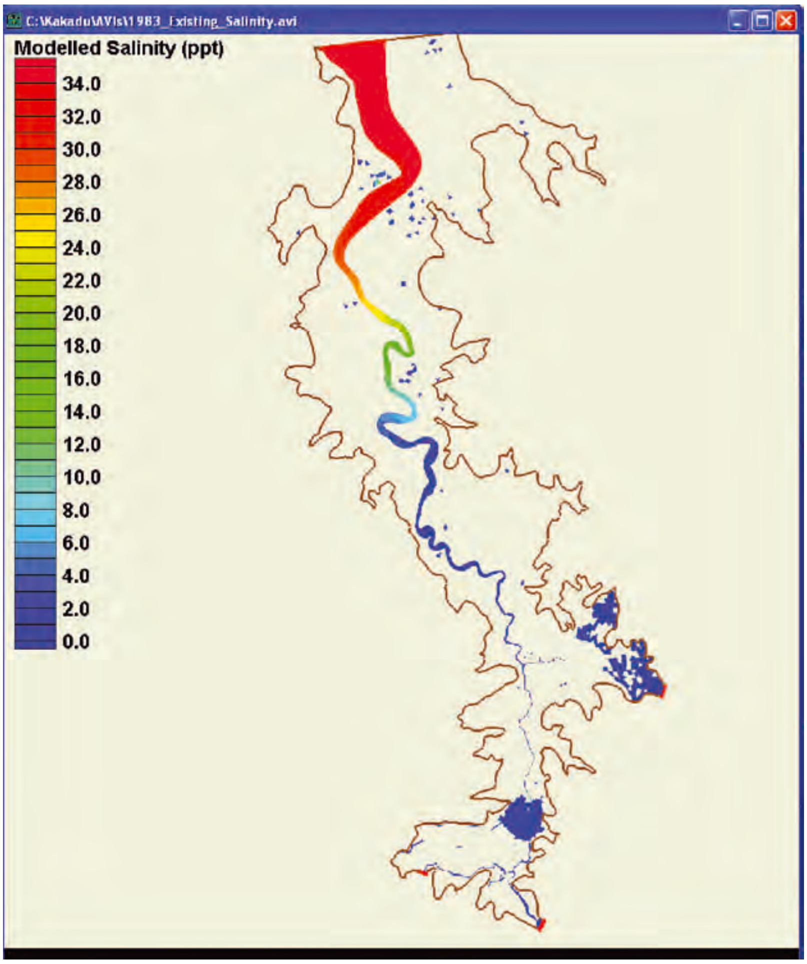

Figure 12: Example of in-channel salinity modelling with no climate change impact

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Appendix L: Key Results Areas and Aims in the Kakadu National Park Management Plan

Success Criteria

Based on the aims in each Key Result Area in the *Kakadu National Park Management Plan 2007–2014*

1	**KRA 1: Natural heritage management**
1.1	Through working with Binninj, the cultural and natural resources of the coastal and marine environment and islands within the Park are recognized, protected and maintained
1.2	The landscapes, soils and water systems of the Park are protected and priority eroded and disturbed areas are rehabilitated
1.3	Through working with Bininj in the active management and use of fire the natural and cultural values of the Park are maintained, and life and property are protected
1.4	Through working with Binij, ecological processes are maintained to ensure the viability of populations of native plants and animals currently occurring in Kakadu
1.5	Access is provided to biological resources while ensuring Park values and the interests of the Director and Bininj are protected
1.6	Economic benefit is gained by Bininj through the sustainable commercial use of native plants and animals for saleable art and craft, for bush tucker tours and other purposes in a manner consistent with Aboriginal cultural practices World Heritage values, the Park leases and the IUCN management principles
1.7	Through working with Bininj, Park values are protected by strategic management of weeds, prevention of invasion of new species, and increased understanding of weed management issues among Park residents, neighbours and visitors
1.8	Through control programs developed and implemented in consultation with Bininj, the adverse effects of domestic and feral animals on the natural and cultural values of the Park, and on human safety are minimized.
2	**KRA 2: Cultural heritage management**
2.1	Bininj cultural heritage is protected and maintained and Bininj guide its management and use
2.2	Through working with Bininj, Aboriginal sites of significance are protected and maintained
2.3	Through working with Bininj, rock art and other archaeological sites are protected and conserved in a manner consistent with national and international obligations
2.4	Post-contact historic sites in Kakadu are adequately recorded and conserved
3	**KRA 3: Joint management**
3.1	KNP is managed to the highest standards that meet expectations of the Australian community for protection of natural and cultural values, and of Bininj traditional owners to meet their obligations to country and satisfy their peoples' aspirations for benefits from land ownership. In doing this, the Director and Binij work together to make shared informed, consistent, transparent and accountable decisions
3.2	Bininj assume more responsibilities related to the administration, control and management of the park and have more opportunities to earn income and gain jobs on country
3.3	Young Bininj learn about their culture and participate in the management of the Park
3.4	Bininj's customary economy continues to contribute to the maintenance of culture and to meeting conservation goals for the Park, in accordance with Aboriginal cultural practices
3.5	Bininj establish living areas in the Park that meet their needs while minimizing the impact on park values

4	**KRA 4: Visitor management and park use**
4.1	KNP is universally recognized as one of the great World Heritage parks, as a place with: a living Aboriginal culture – home to Bininj; extraordinary natural landscapes and a rich variety of plants and animals; enriching and memorable experiences for visitors; and a strong and successful partnership between traditional owners, governments, the tourism industry and Park user groups, providing a world's best practice in caring for country and sustainable tourism
4.2	Visitor experiences are promoted and managed in ways that are culturally and environmentally appropriate
4.3	Road access for residents, visitors and management purposes is provided in a manner that protected Park values and Bininj interests
4.4	A range of recreational and commercial flying opportunities are undertaken in ways that minimize disturbance to residents, visitors and wildlife
4.5	Visitors to Kakadu have a safe and rewarding experience
4.6	A range of camping opportunities are provided that optimize the diversity and quality of visitor experiences while minimizing adverse impacts and protecting Bininj interests
4.7	Visitors to Kakadu have the opportunity to experience Kakadu's habitats through provision of a range of day and overnight walking opportunities in a manner that protects and promotes the natural and cultural values of the Park
4.8	Visitors to Kakadu understand the risks associated with swimming in the Park and risks are appropriately managed
4.9	Opportunities for a range of other recreational activities and public gatherings are provided in a manner that protects park values, Bininj interests and visitor safety
4.10	Visitors enjoy a range of recreational fishing and boating opportunities in a manner that protects Park values and Bininj interests, and minimizes risks to public safety
4.11	Working with Bininj, visitor expectations are appropriately set and the visitor experience is enriched through accurate, high quality information that promotes the World heritage values and management of the Park
4.12	Promotion and marketing of kakadu present accurate and appropriate information and images
4.13	The World Heritage values of the Park and joint management practices are appropriately promote though commercial filming, photography and audio recording
4.14	A range of commercial tour activities provides rewarding experiences for visitors and provides benefits to Binij while protecting interests and minimizing adverse impacts on the natural and cultural values of the Park
4.15	A range of commercial accommodation is provided consistent with protecting the values of the park and providing benefits to Bininj
5	**KRA 5: Stakeholders and partnerships**
5.1	The sustainable development of Jabiru is provided for, while protecting the natural, cultural and World Heritage values of the Park, and the interests of traditional owners and other relevant Aboriginals, and without the town impacting on the Director's resources
5.2	Cooperative relations and partnerships are developed and maintained with Park neighbours and stakeholders in a manner that focuses on promoting the joint management of the Park and achieving common management aims
6	**KRA 6: Business management**
6.1	Capital works and infrastructure are safe, functional and cost effective to construct and maintain and are developed and maintained in a manner that protects Park values
6.2	There is a maximum compliance with relevant legislation as a result of effective education and enforcement programs
6.3	The likely impacts of proposed actions on park values and Bininj interests are properly considered before decisions are made
6.4	Incidents and emergencies in the Park are responded to promptly, effectively and safely
6.5	Leases, subleases or licences, and the management of associated occupancy issues, are provided for appropriately
6.6	Research and monitoring activities in the Park: lead to a better understanding of the Park's biodiversity and natural and cultural heritage values; effectively involve Binnij and traditional skills and knowledge; identify changes to the environment in the Park; contribute to effective management of the Park and the region; and indicate the effectiveness of management actions in protecting the Park values
6.7	Reduce the Park's ecological footprint through the use of best environmental practices in relation to use of resources
6.8	The Director and the Board are able to respond to new issues and proposal consistent with this Plan and the EPBC Act and Regulations
6.9	This Plan is effectively implemented

Appendix M: Initial Risk Register

Initial Risk Register

RISK	SAR CATCHMENT ZONE WITH HIGHEST RISK LEVEL	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO DECR. RAINFALL LIKELI-HOOD	CONSEQUENCE	RISK LEVEL
ECOLOGICAL VALUES				
Decrease in freshwater flora extent	Floodplain	Possible	Major	High
	Upper Estuary	Almost certain	Moderate	High
	Freshwater	Unlikely	Moderate	Medium
Loss of existing magpie goose feeding areas	Floodplain	Possible	Major	High
Loss of pig-nosed turtle habitat	Freshwater	Unlikely	Minor	Low
Decrease in potodramous fish	Floodplain	Possible	Moderate	Medium
Decrease in freshwater crocodile abundance	Upper Estuary	Likely	Moderate	High
	Floodplain	Possible	Moderate	Medium
	Freshwater	Unlikely	Minor	Low
Decrease in monsoon rainforest extent	Floodplain	Possible	Moderate	Medium
Decrease in woodland extent	Floodplain, Freshwater	Rare	Minor	Low
Reduced saltwater crocodile reproductive success	Lower Estuary, Upper Estuary	Possible	Minor	Medium
Reduced barramundi reproductive success	Floodplain, Freshwater	Possible	Moderate	Medium*
Decreased yellow chat abundance	Floodplain, Upper Estuary	Possible	Moderate	Medium
Reduced estuarine/marine flora and fauna abundance	Lower Estuary, Upper Estuary, Coastal	Unlikely	Insignificant	Low
CULTURAL VALUES				
Road access may be increasingly cut to bush tucker, sacred sites, archaeological sites and outstations	Upper Estuary	Likely	Major	High
More intense and frequent storms cause damage to archaeological sites, sacred sites and outstations	Predominantly catchment-wide	Possible	Major	High
Water inundation damages archaeological sites, sacred sites and outstations	Freshwater	Possible	Moderate	Medium
Increasing salinity damage bush tucker availability	Upper Estuary	Likely	Moderate	High
Land degradation makes it difficult to care for country and harvest resources		Possible	Moderate	Medium
SOCIO-ECONOMIC VALUES				
Mining				
More intense and frequent storms cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts in the South Alligator Valley	Freshwater	Possible	Moderate	Medium
Road access may be cut to mine and rehabilitation sites in the South Alligator Valley	Freshwater	Rare	Insignificant	Low
More intense and frequent storms cause damage to infrastructure at Koongarra (should mine become operational- note this is purely hypothetical)	Freshwater	Possible	Moderate	Medium
Small Business				
Road access may be cut to small businesses operating in the SAR	Upper Estuary	Likely	Minor	Medium
More intense and frequent storms cause damage to small business infrastructure	Predominantly catchment-wide	Possible	Minor	Medium

	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO			2070 SLR (700 MM) + 2070 CYCLONE SCENARIO					
	INCR. RAINFALL			DECR. RAINFALL			INCR. RAINFALL		
	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL	LIKELI-HOOD	CONSE-QUENCE	RISK LEVEL
	Possible	Moderate	Medium	Likely	Major	High	Likely	Moderate	High
	Likely	Moderate	High	Almost certain	Moderate	High	Almost certain	Moderate	High
	Rare	Moderate	Low	Possible	Moderate	Medium	Unlikely	Moderate	Medium
	Possible	Moderate	Medium	Almost certain	Major	High	Almost certain	Major	High
	Rare	Minor	Low	Possible	Minor	Medium	Unlikely	Minor	Low
	Possible	Moderate	Medium	Likely	Major	High	Likely	Major	High
	Likely	Moderate	High	Almost certain	Moderate	High	Almost certain	Moderate	High
	Possible	Minor	Medium	Likely	Moderate	High	Likely	Minor	Medium
	Rare	Minor	Low	Possible	Minor	Medium	Unlikely	Minor	Low
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Moderate	High
	Rare	Minor	Low	Unlikely	Minor	Low	Unlikely	Minor	Low
	Possible	Minor	Medium	Possible	Moderate	Medium	Likely	Major	High**
	Possible	Minor	Medium	Likely	Moderate	High*	Likely	Minor	Medium
	Possible	Minor	Medium	Likely	Moderate	High	Likely	Minor	Medium
	Unlikely	Insignificant	Low	Possible	Insignificant	Low	Possible	Insignificant	Low
	Likely	Major	High	Almost certain	Major	Extreme	Almost certain	Catastrophic	Extreme
	Possible	Major	High	Possible	Major	High	Likely	Catastrophic	Extreme
	Possible	Moderate	Medium	Likely	Major	High	Likely	Major	High
	Possible	Moderate	Medium	Almost certain	Major	Extreme	Possible	Major	High
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Moderate	High
	Rare	Moderate	Medium	Rare	Moderate	Medium	Likely	Major	High
	Possible	Moderate	Medium	Rare	Insignificant	Low	Likely	Moderate	High
	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Moderate	High
	Likely	Minor	Medium	Almost certain	Minor	Medium	Almost certain	Minor	Medium
	Possible	Minor	Medium	Possible	Minor	Medium	Likely	Minor	Medium

		2030 SLR (143 MM) + 2030 CYCLONE SCENARIO			
		DECR. RAINFALL			
RISK	SAR CATCHMENT ZONE WITH HIGHEST RISK LEVEL	LIKELI-HOOD	CONSEQUENCE	RISK LEVEL	
Tourism					
Road access may be cut to major tourism attractions including Jim Jim Falls, Twin Falls, Maguk, Gunlom, Koolpin Gorge		Unlikely	Moderate	Medium	
Saltwater intrusion damages tourist attraction (Yellow Water, South Alligator floodplain) and icon species (Brolga, magpie goose, jabiru)	Upper Estuary	Likely	Major	High	
More intense and frequent storms cause damage to infrastructure, tourism attractions (eg art sites), restrict visitor days, threaten visitor safety and create bad publicity		Possible	Moderate	Medium	
Salt water crocodiles expand range into traditional swimming billabongs		Unlikely	Moderate	Medium	
Degradation of natural and cultural values (from storm damage and salt water intrusion) results in a loss of World Heritage status for Kakadu		Unlikely	Moderate	Medium	
Increase in mosquito populations increase health risk and nuisance (for visitors and residents)		Possible	Minor	Low	
Damage to fish nurseries and populations damages recreational fishing (tours & independent) values		Possible	Moderate	Medium	
Increased salinity changes target species for fishermen		Possible	Minor	Medium	
Lower visitor numbers causes a decrease in permanent / seasonal jobs		Possible	Moderate	Medium	
Increase in usage of existing accessible areas and disturbance of new areas to meet the tourism demand		Possible	Minor	Medium	
General Infrastructure / Services					
Increase in infrastructure that is no longer fit-for-purpose	Floodplain, Lower Estuary	Unlikely	Insignificant	Low	
	Freshwater	Rare	Insignificant	Low	
PLANNING AND REGULATION					
Increase in developments being approved/built in inappropriate places due to lack of available information, and triggers in legislation		Unlikely	Minor	Low	
Increase in current approved/lawful development becoming inappropriate		Rare	Insignificant	Low	
Increase in requirements for ongoing management and planning resources within KNP		Unlikely	Insignificant	Low	
PLANNING AND REGULATION					

* due to reduced riverine-floodplain connectivity (coupled with SLR)

** due to increased flooding (coupled with SLR)

	2030 SLR (143 MM) + 2030 CYCLONE SCENARIO			2070 SLR (700 MM) + 2070 CYCLONE SCENARIO					
	INCR. RAINFALL			DECR. RAINFALL			INCR. RAINFALL		
	LIKELIHOOD	CONSEQUENCE	RISK LEVEL	LIKELIHOOD	CONSEQUENCE	RISK LEVEL	LIKELIHOOD	CONSEQUENCE	RISK LEVEL
	Possible	Moderate	Medium	Unlikely	Moderate	Medium	Likely	Moderate	High
	Likely	Major	High	Almost certain	Major	Extreme	Almost Certain	Major	Extreme
	Possible	Moderate	Medium	Possible	Moderate	Medium	Likely	Major	High
	Unlikely	Moderate	Medium	Possible	Moderate	Medium	Possible	Moderate	Medium
	Unlikely	Moderate	Medium	Unlikely	Moderate	Medium	Unlikely	Moderate	Medium
	Possible	Minor	Medium	Possible	Minor	Medium	Likely	Minor	Medium
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Moderate	High
	Possible	Minor	Medium	Possible	Minor	Medium	Possible	Minor	Medium
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Major	High
	Possible	Moderate	Medium	Likely	Moderate	High	Likely	Major	High
	Possible	Minor	Medium	Unlikely	Insignificant	Low	Likely	Moderate	High
	Possible	Minor	Medium	Rare	Insignificant	Low	Likely	Moderate	High
	Unlikely	Major	Medium	Possible	Minor	Medium	Possible	Major	High
	Possible	Moderate	Medium	Unlikely	Minor	Low	Likely	Major	High
	Possible	Moderate	Medium	Possible	Minor	Medium	Likely	Major	High

Appendix N: Detailed Risk Analyses

Risk Assessment table

Issue codes

ID	DESCRIPTION
C	Coastal
F	Floodplain
FW	Freshwater
LE	Lower Estuary
UE	Upper Estuary
X	Catchment wide

Impact parameters

IMPACT PARAMETER	COAST	FLOODPLAIN	FRESHWATER	LOWER ESTUARY	UPPER ESTUARY
Sea level Rise (including storm surge)					
1. Increased salt intrusion by levee overtopping	**C1**	**F1**	**FW1**	**LE1**	**UE1**
2. Increased channel expansion (including dendritic channels)	**C2**	**F2**	**FW2**	**LE2**	**UE2**
3. Increased salinity	**C3**	**F3**	**FW3**	**LE3**	**UE3**
Decreased rainfall					
4. Increased length of dry season	**C4**	**F4**	**FW4**	**LE4**	**UE4**
5. Increased salinity	**C5**	**F5**	**FW5**	**LE5**	**UE5**
6. Decreased flooding events	**C6**	**F6**	**FW6**	**LE6**	**UE6**
Increased rainfall					
7. Decreased length of dry season	**C7**	**F7**	**FW7**	**LE7**	**UE7**
8. Decreased salinity	**C8**	**F8**	**FW8**	**LE8**	**UE8**
9. Increased flooding events	**C9**	**F9**	**FW9**	**LE9**	**UE9**

Ecological values

Risk E1: Decrease in freshwater flora extent

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario			UE					UE		
									F	
				F				FW		
			FW							
Increased Rainfall Scenario								UE		
			UE					F		
			F							
								FW		
			FW							

- Impact parameters: F1, F2, F3, F4, F5, F6, UE1, UE2, UE3, UE4, UE5, UE6, FW1, FW2, FW3, FW4, FW5, FW6
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of detailed habitat and vegetation community mapping; lack of physiological tolerance data for freshwater flora species; lack of knowledge of vegetation colonization timeframes

Risk E2: Loss of existing magpie goose feeding areas

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario									F	
				F						
Increased Rainfall Scenario									F	
			F							

- Impact parameters: F1, F2, F3, F4, F5, F6, F7, F8, F9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Limited knowledge on physiology and tolerance limits of plant species used as food resources; limited quantitative knowledge on magpie goose population statistics; lack of documented spatial data of magpie geese feeding areas; lack of knowledge of vegetation colonization timeframes

Risk E3: Loss of pig-nosed turtle habitat

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
							FW			
		FW								
Increased Rainfall Scenario										
							FW			
		FW								

- Impact parameters: FW1, FW2, FW3, FW4, FW5, FW6
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Limited knowledge on physiological tolerance limits and environmental requirements of pig-nosed turtle; lack of quantitative knowledge on pig-nosed turtle population statistics; lack of documented pig-nosed turtle spatial data; lack of knowledge of vegetation colonization timeframes

Risk E4: Decrease in potodramous fish abundance

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
									F	
			F					FW		
				FW						
Increased Rainfall Scenario										
									F	
			F					FW		
				FW						

- Impact parameters: F1, F2, F3, F4, F5, F6, FW1, FW2, FW3, FW4, FW5, FW6
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Limited knowledge on physiological tolerance limits of species

Risk E5: Decrease in freshwater crocodile abundance

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario								UE		
			UE					F		
			F				FW			
		FW								
Increased Rainfall Scenario								FW		
			UE				F			
		F								
							FW			
		FW								

- Impact parameters: F1, F2, F3, F4, F5, F6, F7, F9, FW1, FW2, FW3, FW4, FW5, FW6, FW7, FW9, UE1, UE2, UE3, UE4, UE5, UE6, UE7, UE9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of quantitative knowledge on freshwater crocodile population statistics; lack of documented freshwater crocodile spatial data; lack of knowledge of vegetation colonization timeframes

Risk E6: Decrease in monsoon rainforest extent

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario							UE			
		UE						F		
			F							
Increased Rainfall Scenario							UE			
		UE						F		
			F							

- Impact parameters: F1, F2, F3, F4, F9, UE1, UE2, UE3, UE4, UE9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of physiological tolerance data for monsoon rainforest flora species

Risk E7: Decrease in woodland extent

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
							F, FW			
		F, FW								
Increased Rainfall Scenario										
							F, FW			
		F, FW								

- Impact parameters: F1, F2, F3, F9, FW1, FW2, FW3, FW9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of physiological tolerance data for woodland flora species

Risk E8: Reduced saltwater crocodile reproductive success

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								LE, UE[2a], F3[b]		
	C[1]	LE, UE[2]				C[1]		FW[3b]		
Increased Rainfall Scenario										
		LE, UE[2]						F[3a,b]	LE, UE[2a]	
	C[1]	F[3a,b]				C[1]				
		FW[3a,b]						FW[3a]		

- Impact parameters: C1, C2, C3, F1, F2, F3, F4, F5, F6, F7, F9, FW1, FW2, FW3, FW4, FW5, FW6, FW7, FW9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of knowledge of saltwater crocodile prey values (freshwater versus marine); lack of knowledge of vegetation colonization timeframes; lack of quantitative knowledge on saltwater crocodile population statistics; lack of documented saltwater crocodile spatial data

Impacts due to levee overtopping & saltwater intrusion:

1. Coastal fringe is not considered to be a key nesting area (mangroves, saltpan)
2. Key nesting areas. Assumes more frequent inundation of nesting sites
   a. Changes in vegetation (replacement of freshwater wetland with mud flats, saltmarsh or mangroves). Also assumes no major changes in relief
3. Contains marginal nesting sites
   a. Nest sites subject to increased flooding/inundation
   b. Nesting sites subject to increased saltwater inundation, and assumes a shift in nesting sites to upstream areas

Risk E9: Reduced barramundi reproductive success

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
							LE, UE[1,2,3,4]	F, FW[2,3,4]		
		LE, UE[1,2,3,4]	F, FW[2,3,4]							
		C[1,2]								
Increased Rainfall Scenario							LE, UE[1,2,3] F, FW[2,3]			
		LE, UE[1,2,3] FW[2,3], F[2,3]								
		CI[1]					C[1,2]			

- Impact parameters: C1, C2, C3, LE1, LE2, LE3, UE1, UE2, UE3, UE4, UE5, UE6, UE7, UE8, UE9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of knowledge of barramundi prey values (freshwater versus marine); lack of knowledge of vegetation colonization timeframes; lack of quantitative knowledge on barramundi population statistics
  1. Potential increase in spawning habitat
  2. Loss of adjacent nursery habitat (freshwater wetlands) due to SLR
  3. Change in prey types, competition and other interactions due to SLR
  4. Loss of floodplain connectivity due to low rainfall

NB: For all increased rainfall scenarios, assumes negative impacts due to SLR partly mitigated by increased flows.

Risk E10: Decreased yellow chat abundance

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								F, UE		
			F, UE							
Increased Rainfall Scenario										
							F, UE			
		F, UE								

- Impact parameters: F1, F2, F3, F4, F5, F6, F9, UE1, UE2, UE3, UE4, UE5, UE6, UE9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Limited knowledge on environmental requirements of yellow chat; lack of quantitative knowledge on yellow chat population statistics; lack of documented yellow chat spatial data; lack of knowledge of vegetation colonization timeframes

Risk E11: Reduced estuarine/marine flora and fauna abundance

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
						C, LE, UE				
	C, LE, UE									
Increased Rainfall Scenario										
						C, LE, UE				
	C, LE, UE									

- Impact parameters: C1, C2, C3, LE1, LE2, LE3, LE5, LE6, LE8, LE9, UE1, UE2, UE3, UE5, UE6, UE8, UE9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Lack of detailed habitat and vegetation community mapping; lack of knowledge of vegetation colonization timeframes

Risk E12: Loss of existing magpie goose nesting area

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario									F	
				F						
Increased Rainfall Scenario									F	
				F						

- Impact parameters: F1, F2, F3, F4, F5, F6, F7, F8, F9
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Limited knowledge on physiology and tolerance limits of plant species used as nesting resources; limited quantitative knowledge on magpie goose population statistics; lack of documented spatial data of magpie geese feeding areas.

Risk E13: Reduction in frog abundance

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
									F	
				F						
Increased Rainfall Scenario										
								F		
			F							

- Impact parameters: F1, F2, F3, F4, F5, F6
- Relevant KRAs: N/A – based on impact to value
- Knowledge gaps: Limited knowledge on physiological tolerance limits and environmental requirements of frog species; lack of quantitative knowledge on frog population statistics; lack of documented frog spatial data; lack of knowledge of vegetation colonization timeframes

Cultural Values

Risk C1: Road access may be increasingly cut to bush tucker, sacred sites, archaeological sites and outstations

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario									C, LE, UE	
			C, LE	UE					F	
	FW			F			FW			
Increased Rainfall Scenario									C, LE, UE	
			C, LE	UE					F, FW	
				F, FW						

- Impact parameters: C1, C2, LE1, LE2, UE1, UE2, UE7, UE9, F1, F2, F7, F9, FW7, FW9
- Relevant KRAs: 1.6, 2.1, 2.2, 2.3, 3.3, 3.4, 3.5 4.3
- Knowledge gaps: Locations of sacred sites & archaeological sites

Risk C2: More intense and frequent storms cause damage to archaeological sites, sacred sites and outstations

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
				X					X	
Increased Rainfall Scenario										
									UE, F, FW	
				X					C, LE	

- Impact parameters: UE9, F9, FW9
- Relevant KRAs: 2.1, 2.2, 2.3, 3.3, 3.5
- Knowledge gaps: Locations of sacred sites & archaeological sites

Risk C3: Water inundation damages archaeological sites, sacred sites and outstations

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario								C, LE, UE		
		C, LE, UE							F	
			F							
									FW	
			FW							
Increased Rainfall Scenario								C, LE, UE		
		C, LE, UE							F, FW	
			F, FW							

- Impact parameters:C1, LE1, UE1, UE9, F1, F9, FW9
- Relevant KRAs: 2.1, 2.2, 2.3, 3.3, 3.5
- Knowledge gaps: Locations of sacred sites & archaeological sites

Risk C4: Sea level rises decreases bush tucker availability

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			UE							
									F, FW	
				F, FW						
	C, LE					**C, LE**				
Increased Rainfall Scenario										
			UE						**UE,** F	
				F, FW					FW	
	C, LE					**C, LE**				

- Impact parameters: F1, F3, F4, F5, F6, LE1, LE3, LE4, LE5, LE6, UE1, UE3, Ue4, UE5, UE5, FW1, FW3, FW4, FW5, FW6
- Relevant KRAs: 1.6, 2.1, 3.3, 3.4
- Knowledge gaps: refer to E1-E13

Risk C5: Land degradation makes it difficult to care for country and harvest resources

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								X		
			X							
Increased Rainfall Scenario										
								X		
			X							

- Impact parameters: C1, C2, LE1, LE2, UE1, UE2, UE7, UE9, F1, F2, F7, F9, FW7, FW9
- Relevant KRAs: 1.4, 1.7, 1.8, 3.2
- Knowledge gaps: Refer to E1, E2, E6, E7 and E11

Socio-economic values – mining

Risk S1: More intense and frequent storms cause damage to waste holding facilities, rehabilitation works, tailings areas, mine sites and shafts in the South Alligator Valley

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			FW					FW		
Increased Rainfall Scenario										
			FW					FW		

- Impact parameters: FW9, cyclone scenarios
- Relevant KRAs: 1.2
- Knowledge gaps: Actual risks posed by mining waste

Risk S2: Road access may be cut to mine rehabilitation sites in the South Alligator Valley

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
	FW					FW				
Increased Rainfall Scenario										
								FW		
			FW							

- Impact parameters: FW7, FW9
- Relevant KRAs: 1.2
- Knowledge gaps:

Risk S3: More intense and frequent storms cause damage to infrastructure at Koongarra (should mine become operational- note this is purely hypothetical)

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			FW					**FW**		
Increased Rainfall Scenario										
								FW		
			FW							

- Impact parameters: FW9, cyclone scenarios
- Relevant KRAs: 1.2
- Knowledge gaps: Whether Koongarra will be mined in the future

Risk S17: Road access and product transport is cut to Ranger Mine

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
				LE					**LE**	
Increased Rainfall Scenario										
									LE	
				LE						

- Impact parameters: LE1, LE2, LE7, LE9
- Relevant KRAs: 5.2
- Knowledge gaps:

Socio-economic values- small business

Risk S4: Road access may be cut to small businesses operating in the SAR

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario						C, LE	UE			
	C, LE	UE					F			
	FW	F								
							FW			
Increased Rainfall Scenario						C, LE	UE			
	C, LE	C, LE					F, FW			
		F, FWUE								

- Impact parameters: C1, C2, LE1, LE2, UE1, UE2, UE7, UE9, F1, F2, F7, F9, FW7, FW9
- Relevant KRAs: 1.5, 1.6, 3.5
- Knowledge gaps: Current & potential businesses

Risk S5: More intense and frequent storms cause damage to small business infrastructure

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
		X					X			
Increased Rainfall Scenario										
							UE, F, FE			
		X					C, LE			

- Impact parameters: UE9, F9, FW9, cyclone scenarios
- Relevant KRAs: 1.5, 1.6, 3.5
- Knowledge gaps: Current & potential businesses

Socio-economic values- tourism

Risk S6: Increased incidence of road access being cut to major tourism attractions including Jim Jim Falls, Twin Falls, Maguk, Gunlom, Koolpin Gorge

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			X					X		
Increased Rainfall Scenario										
								X		
			X							

- Impact parameters: FW7, FW9
- Relevant KRAs: 4.3, 4.5
- Knowledge gaps:

Risk S7: Salt water intrusion damages tourist attractions (Yellow Waters, South Alligator flood plain) and icon species (Brolga, magpie goose, jabiru)

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario									UE	
				UE					F	
				F					FW	
				FW						
Increased Rainfall Scenario									UE	
				UE					F	
				F					FW	
				FW						

- Impact parameters: UE1,2,3,4,5,6,7,8,9; F1,2,3,4,5,6,7,8,9; FW1,2,3,4,5,6,7,8,9
- Relevant KRAs: 1.2, 1.4, 4.1, 4.5
- Knowledge gaps: Limited spatially referenced ecological data and mapping; limited life history knowledge for most species; limitations of modeling (DEM etc.)

Risk S8: More intense and frequent storms cause damage to infrastructure, tourism attractions (e.g. art sites), restrict visitor days, threaten visitor safety and create bad publicity

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			X					X		
Increased Rainfall Scenario										
									X	
			X							

- Impact parameters: UE9, F9, FW9, cyclone scenarios
- Relevant KRAs: 4.1, 4.5, 4.12
- Knowledge gaps:

Risk S9: Increased incidence of salt water crocodiles preventing access to swimming billabongs (visitor dissatisfaction)

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								X		
			X							
Increased Rainfall Scenario										
								X		
			X							

- Impact parameters: FW2, FW7, FW9
- Relevant KRAs: 4.5
- Knowledge gaps: Modelling; prey values (freshwater versus marine); vegetation colonization timeframes

Risk S10: Degradation of World Heritage natural and cultural values (from storm damage and salt water intrusion)

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			X					X		
Increased Rainfall Scenario										
			X					X		

- Impact parameters:
- Relevant KRAs: 1.2, 1.4, 2.1, 4.1, 4.5
- Knowledge gaps: Importance of World Heritage status for visitors

Risk S11: Increase in mosquito populations increases health risk and nuisance (for visitors and residents)

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
			X					X		
Increased Rainfall Scenario										
			X					X		

- Impact parameters: C2, LE2, UE2, UE9, F9, FW9
- Relevant KRAs: 3.5, 4.5
- Knowledge gaps: Mosquito population biology

Risk S12: Damage to fish nurseries and populations damages recreational fishing (tours & independent) values

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								X		
			X							
Increased Rainfall Scenario										
								X		
			X							

- Impact parameters: C1; C2; C3; LE1; LE2; LE3; UE1; UE2; UE3; UE4; UE5; UE6; UE7; UE8; UE9
- Relevant KRAs: 4.10
- Knowledge gaps: Modelling; prey values (freshwater versus marine); vegetation colonization timeframes

Risk S13: Increased salinity changes target species for fishermen

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
		X					X			
Increased Rainfall Scenario										
		X					X			

- Impact parameters: C1; C2; C3; LE1; LE2; LE3; UE1; UE2; UE3; UE4; UE5; UE6; UE7; UE8; UE9
- Relevant KRAs: 4.10
- Knowledge gaps: Modelling; prey values (freshwater versus marine); vegetation colonization timeframes

Risk S14: Lower visitor numbers causes a decrease in permanent / seasonal jobs

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								X		
			X							
Increased Rainfall Scenario										
									X	
			X							

- Impact parameters: All
- Relevant KRAs: 4.1, 4.14
- Knowledge gaps:

Risk S15: Increase in usage of existing accessible areas and disturbance of new areas to meet the tourism demand

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
								X		
		X								
Increased Rainfall Scenario										
									X	
			X							

- Impact parameters: All
- Relevant KRAs: 4.1, 4.2, 4.5, 4.8, 4.10
- Knowledge gaps:

Socio-economic values- general infrastructure/ services

Risk S16: Infrastructure increasingly unfit for purpose

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
	F, LE					F, LE				
	FW					FW				
Increased Rainfall Scenario										
								F, LE, FW		
		F, LE, FW								

- Impact parameters: F1, F6, F9, LE1, LE6, LE9, FW1, FW6, FW9
- Relevant KRAs: n/a – based on impact to value
- Knowledge gaps: exact location of infrastructure and schedule for maintenance and upgrades

Planning and Regulation

Risk P1: Increase in developments being approved/ built in inappropriate places due to lack of available information and triggers in legislation

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
							X			
		X								
Increased Rainfall Scenario										
								X		
			X							

- Impact parameters: F1, F6, F9, LE1, LE6, LE9, FW1, FW6, FW9
- Relevant KRAs: n/a – based on impact to value
- Knowledge gaps: information that is available to authorities currently when planning development

Risk P2: Increase in current approved / lawful development becoming inappropriate

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario										
							X			
	X									
								X		
Increased Rainfall Scenario			X							

- Impact parameters: F1, F6, F9, LE1, LE6, LE9, FW1, FW6, FW9
- Relevant KRAs: n/a – based on impact to value
- Knowledge gaps: the elevation of current development

Risk P3: Increase in requirements for ongoing management and planning resources within KNP

	2030 SLR (143 MM) + 2030 STORM SURGE INCREASE					2070 SLR (700 MM) + 2070 STORM SURGE INCREASE				
Decreased Rainfall Scenario							X			
	X									
								X		
Increased Rainfall Scenario			X							

- Impact parameters: All
- Relevant KRAs: All
- Knowledge gaps:

Appendix O: Adaptation Options Toolshed

Adaptation Options 'Toolshed'

TREATMENT TYPE	ADAPTATION OPTION
Spread risk	**Natural** Identification and protection of upstream natural/existing refugia for freshwater species and communities Identification of sacrificial sites (e.g. lower cultural/natural value)
	Social/Economic/Infrastructure Identification and protection of new/alternative tourism sites Expand and diversify business opportunities for tour operators and small businesses Expand and diversify tourism experiences and locations (i.e. open up new areas for tourism purposes) Diversity tourism experiences (e.g. Kakadu in the wet, year round cultural experiences) Increase boat-based tourism Identification of sacrificial tourism sites (to reduce pressure on other sites) Changing the use of resources for small businesses (e.g. use of natural products that are no longer available)
Structural and technological	**Physical Process** Construction of small barrages (artificial sills) on dendritic channels to prevent saltwater inundation Artificial maintenance and/or elevation of natural levees (possibly through side-casting from a dredge) Habitat creation/use of degraded habitats (e.g. dig a hole or use existing gravel pits) either in floodplain or in freshwater areas Construction of a major barrage between the tidal head and Yellow Water (approx 1m high and 800m wide) Construction of a major barrage at the South Alligator bridge Construction of floodplain storage/detention basin in the lower estuary (i.e. Create a large hole for the saltwater to fill) Pump saline water out of freshwater billabong (into sacrificial billabong) and pump freshwater into billabongs from upstream (i.e. Dilute the salty water) Use environmental flow regulation/release in dry periods to ensure the low salinity levels /flushing is maintained in high risk areas. Artificial irrigation of monsoon rainforests Dewater sites that become temporarily flooded (from SLR or rainfall)
	Natural Fish stocking and introduction of other species into upstream refugia Maintenance of high value habitat areas Enhancement and rehabilitation of previously degraded habitat (e.g. following impacts from buffalo) Enhancement and rehabilitation of habitats impacted by climate change impacts Removal of mangroves that are encroaching on other communities (e.g. saltmarsh) Maintain/change vegetation on an capped areas (e.g. landfill/waste disposal sites, contaminated sites, and in the future, potential new mine sites)
	Cultural Build a wall/bund around cultural sites to protect from saltwater inundation and/or flooding Protection of priority art sites Find alternative methods to access cultural sites Enhancement and rehabilitation of hunting sites impacted by climate change impacts Translocation of bush tucker species Maintenance of representative examples of cultural heritage sites

TREATMENT TYPE	ADAPTATION OPTION
	Social/Economic/Infrastructure Modify access routes (including new routes, increase in road heights, more culverts) Build better creek/river crossings (e.g. change structure to bridge rather than causeway) Increase drainage infrastructure Increase the design criteria in applicable standards/codes/regulation (e.g. 300mm above 1% AEP) Build 'substratum plug' (wall down to rock bed) around mine sites (including future sites) and/or contaminated sites Strip capping and cap with an alternative material currently capped areas (e.g. landfill/waste disposal sites, contaminated sites, and in the future, potential new mine sites) Provision of desalination plants for potable water purification Provision of rainwater tanks on all residential, commercial and Park buildings Installation of packaged sewage treatment plants Spray for mosquitoes Maintenance of high value tourism areas Provide/upgrade evacuation routes (e.g. evacuation for storm surge events)
Regulatory and institutional	**Natural** Develop site based management strategy for high value and high risk sites to mitigate potential threatening process/climate change impact Review conservation status of species (taking into account predicted climate change impacts) Review regulatory provisions related to commercial/other activities that may impact vulnerable habitats/species Ensure implementation of relevant actions in species recovery plans/action plans/strategies Introduce access restrictions to particular areas to build resilience to climate change
	Cultural Indigenous agreements to limit traditional hunting of high risk species (i.e. those under significant pressure from climate change impacts) Develop site based management strategy for high value and high risk sites to mitigate potential threatening process/climate change impact
	Social/Economic/Infrastructure Develop billabong strategies for tourism purposes (i.e. when to abandon, when to identify new location for tourism activity) Provide a tourist 'cap'/limit numbers of tourists accessing key sites Increase health programs and the availability of appropriate medications Upgrade emergency procedures (e.g. evacuation for storm surge events) Regular studies to update design levels for flooding and storm surge in regulation (and application of these regulations in the South Alligator River catchment). Reintroduce Park user fees (user pays principle) to provide funding for implementation of adaptation options to climate change impacts Provide additional resources (e.g. personnel, funding, time) or access alternative resources (e.g. from outside Kakadu) to provide required planning for and management of climate change impacts Develop site based management strategy for high value and high risk sites to mitigate potential threatening process/climate change impact
Avoidance	**Cultural** Relocate outstations
	Social/Economic Relocate mining facilities Relocate tourism infrastructure with changing habitat use/impacts on natural/cultural values

TREATMENT TYPE	ADAPTATION OPTION
Research	**Natural** Provide/increase monitoring and research of key gaps in information that would provide better information for assessing the potential impact and risk of climate change (e.g. flows/rainfall, habitat mapping, salinity levels in the estuary, topography, regular surveys of indicator species) Increase research on priority species and habitats identified in action plans Carry out a detailed risk assessment per high value and high risk site
	Cultural Identification of priority art sites that may require protection Provide/increase monitoring and research of key gaps in information that would provide better information for assessing the potential impact and risk of climate change (e.g. use of bush tucker sites, condition of art and archaeological sites) Carry out a detailed risk assessment per high value and high risk site
	Social/Economic/Infrastructure Identify small business opportunities that may be presented by climate change impacts Provide/increase monitoring and research of key gaps in information that would provide better information for assessing the potential impact and risk of climate change (e.g. Park visitation, contribution of KNP to NT economy for cost-benefit analysis) Carry out a detailed risk assessment per high value and high risk site Develop accurate Digital Elevation Model (DEM) to feed into future risk assessments land use planning
Educational, behavioural	**Natural** Provide education on key species/habitats and how they may be affected by climate change impacts Provide education/information on a storm, cyclone and flood awareness relevant at a local scale (ie. areas likely to have increased impacts)
	Cultural Provide education with regard to bush tucker species (particularly those that are becoming threatened) and how they may be affected by climate change impacts Follow traditional customs with regard to bush tucker species (ie. not ‘free for all’)
	Social/Economic Market tourism differently (i.e. ‘black’ tourism) to change people’s perception about climate change impacts (ie. come to Kakadu to see what impacts climate change is having) Market tourism differently to promote the urgency to see Kakadu before it is impacted by climate change Market tourism differently to promote the benefits of climate change impacts (e.g. saltwater crocodiles in new/more locations, new species and communities) Education of tourists regarding environmentally responsible behaviour to improve resilience of sites Provide information to small businesses and tour operators to allow them to adapt to the changing nature of business and tourism

Appendix P: Adaptation Options for each Identified Risk

RISK ID	ADAPTATION OPTION
ECOLOGICAL VALUES	
E1	1. Identify key sites (refugia) and values, and examine opportunities to spread risks. This should be based on: a. Review existing information. Suggestion that baseline data was collected in 1970's for assessing impacts of uranium mine b. Undertake gap analysis to identify needs for further data collection c. Collect data to in-fill gaps
	2. Assess risks to key sites through: a. Collect topographic data and develop Digital Elevation Model (DEM) b. Undertake hydraulic modeling c. Undertake ecological response modeling
	3. Develop management plan (or other strategy as required) incorporating management strategies (expedite process and lock in contractors to do work)
	4. Undertake engineering works (e.g. levee construction at highway bridge; offshore barrier to reduce saltwater inflow volumes) to protect high priority areas, which will involve: a. Preliminary feasibility studies b. Small scale trials if shown to be feasible c. If shown to be feasible, construct and maintain levee structure d. Monitor effectiveness of structure
	5. Build resilience in refugia. This could involve: a. Weed control b. Strict enforcement to manage impacts at high priority sites c. Visitor management to manage impacts at high priority sites
E2	See all options for E1.
	In terms of building resilience, undertake measures to protect remaining population through habitat protection and sustainable harvest
E3, E5	See all options for E1
	In terms of building resilience, in addition to the above mentioned works, also assess opportunities for captive breeding program to supply food to traditional owners
E4, E9	See all options for E1
	In terms of building resilience, in addition to the above mentioned works, also assess opportunities for captive breeding program to stock high value habitats that may be damaged by Sea Level Rise
	Assess opportunities for constructing structures (weirs) to create flood storage that can be used to replenish downstream environments (i.e. environmental flow release). This would need to involve feasibility works/trials similar to described for engineering works (aquatic macrophytes)
E8	See all options for E1
	There was a general view that crocodile populations will look after themselves – self regulation. But there was a need to go through a process to assess and manage risk.
	Visitor management seen as a key priority in terms of protecting any critical sites
E10	See all options for E1
	In terms of building resilience, in addition to the above mentioned works, also assess opportunities for captive breeding program (if required)
E11	Determined will look after itself

RISK ID	ADAPTATION OPTION
CULTURAL VALUES	
C1	DEM and monitoring to determine risk and demand
	Relocating roads
	Upgrading roads
	Alternative access to sites
C2, C3	DEM and monitoring
	Identify key sites (refugia) and values and spreading risks
	Review of existing information – baseline 1970's
	Monitoring
	Collect topographic data (DEM) to identify at risk sites
	Protect against exposure
	Improve art site management
	Collect/move artifacts (in consultation with traditional owners)
C4	Identify key sites (refugia) and values and spreading risks
	Review of existing information – baseline 1970's
	Monitoring
	Collect topographic data (DEM) to identify at risk sites
	Management plan (or other strategy as required) incorporating mgt strategies (expedite process and lock in contracts)
	Levee construction to protect high priority sites (e.g. at highway bridge) – pending engineering analysis
	Build resilience in refugia (e.g. weed control)
	Enforcement – fines – protect habitats from recreational fishers
	Visitor management
	Offshore barrier – reduce saltwater inflow volumes
	Maintain customary practices
	Consistent policy across Northern Territory – legislative review
	Build resilience by - Increase enforcement/education/management
	Farming? e.g. Nursery for lilies
SOCIO-ECONOMIC VALUES	
1. Mining	
S1	Bureau of Meteorology refreshed data set Building code being reviewed Australian Rainfall and Runoff (ARR) guide
	Location of past facilities Extractive, gravel pits, small mines, exploration areas (damage) Review and risk assessment by Northern Territory (DRPIFR) or Federal Government
	Determine priority rehabilitation areas
	Current rehabilitation projects modeled for use at other sites
S2	(Already have adaptive strategy for only accessing during the dry)
	Future planning take into account Sea Level Rise (not big issue at the moment)
	Raising road and appropriate infrastructure (culvert vs. bridge)
	Build capacity for Fly In Fly Out

RISK ID	ADAPTATION OPTION
S3	Consensus – Not happening
S17	‘Plan B’ route and provision of information
	Fly In Fly Out – products and people
	Rebuild acid plant
	Alternative energy for the mine
	Alternative energy for the Park (e.g. hydro-electricity)
2. Small Business	
S4	Business model adapted to climate change (e.g. shorter periods of access), split into development and implications
	More ‘bang for your buck’ in shorter season/ time – consideration- included in climate change adapted business model Define how to get greater yield out of same (or less) number of people
S5	Future planning for new businesses including: Identification of specified sites for re-locatable structures Facility design i.e. waste to consider climate change
3. Tourism	
S6	Look at options for updating Pine Creek access
	All weather road access (build resilience in current road access)
	Identify key sites (and gradual increase in access to these sites)
S7	Living museum
	Managing visitor expectation and appropriate interpretation
	Relocate sits for tourism to maintain experience (and identify those areas)
	Adapt product offered
	Provide information for business planning (‘Plan B’) e.g. impacts of big events – i.e. disastrous events (tourism impact = disastrous)
	Through tourism accreditation process, ensure businesses have review process NB: Accreditation is like a toolkit and climate change should be taken into account in usual business planning processes
S8	Manage Public Relations associated with events
	Information on why sites/roads are closed- communications
	Disaster risk management plan/incident response plan Considers – people throughout the park (tourist areas, outstations, etc)
	Review current Disaster plan/Incident Response Plan
	Integrate emergency management with other services
	Ensure stakeholders outside park are aware of responsibilities under plan
	Build refuge areas/cyclone shelters Purpose – built shelters
	Mechanisms to determine thresholds for safety (e.g. temperature, water supply) and review of thresholds

RISK ID	ADAPTATION OPTION
S9	Safari hunting
	Culling by Parks Australia – determining point at which becomes impossible to manage
	Look at mechanisms to manage visitor expectations. i.e. can't swim in park anymore
	Crocodile-proof cages
	Education in schools/visitor centre
	Closing areas to swimming
	Put in swimming pools
	Council to also put out information/educational material Work collectively with Parks/joint responsibility
	More resources into crocodile management
	Find new opportunities- i.e. different type of visitor experiences (not necessarily new sites)
	Modeling to determine required levels for future road upgrades (data collection, review of standards)
	Fly in Fly Out (and other alternate forms of transport) to locations and use appropriate vehicles within these locations
	Building flexibility in tourism business and manage tourism expectations
	Provide information to tourists on alternate routes
	Review mechanisms for providing information to tourists on alternate routes/weather conditions/ water levels/ site damage etc.
	Develop communications strategy
S10	Information on World Heritage criteria and assess criteria most at risk
	Determine/identify priority sites for protection
	Extreme management/structural protection of key sites
	Alternative sites
S11	Health dept planning for screening of visitors
	Education regarding clothing, time of day etc.
	Increased research into appropriate drugs (and availability) e.g. anti-malarials and treatment options
	More information regarding new threats/problem species (e.g. sandflies) Potentially provided by Medical Entomology Section of Health Department
	Free repellent (DEET) with each Park Pass
S12	Fish stocking (supplementary)/ Aquatic programs (no current fish stocking program)
	Alternative programs/attractions and liaise with competition organizers
	Enforced catch and release Could include catch, tag and release for scientific purposes
	Stop recreational fishing in the Park (take of native species)
	Add additional conditions to permits for fishing comps/tours
	Lobby NT Government – regulation change – size and bag limits
	Enforcement increase (NT Government)
	License for recreational fishers
S14	Look into transition people into new jobs/providing training to industries not impacted by climate change
	Increase wages for seasonal staff (earn more in less time)
	Approach mining industry for other seasonal (wet) jobs to offset loss in other industries

RISK ID	ADAPTATION OPTION
S15	Area planning needs to consider – capacity
	Infrastructure development
	Alternative experiences
4. General Infrastructure/Services	
S16	Regulation and design guidelines to consider CC
	Retrofitting
	Research done to look at best practice
PLANNING AND REGULATION	
P1	Centralised (NT Government) planning including: Flood and storm surge risk map Mosquito map/ different mosquito species and different management methods for different species
	Audit of existing policy and procedures and overlay range of impacts – gap analysis
	Process to fill identified gaps
P2	Structural intervention
	Adapt design of existing infrastructure
	Relocating/Retreat
P3	Review current review processes to determine if sufficient to take into account changes in climate change information

Notes at end of table:

- Land degradation (decreased management)
- Build resilience by active management (as per existing)

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