Please quote: 1280942 TS:kb

3 July 2008

Discussion Paper on NT Climate Change Issues
Department of the Chief Minister
GPO Box 4396
DARWIN NT 0801

By Email: climatechange.dcm@nt.gov.au

Dear Sir\Madam,

Northern Territory Government Discussion Paper On Climate Change Issues

Darwin City Council is pleased to have the opportunity to respond to the discussion paper on Northern Territory Climate Change Issues makes the following comments.

Council agrees that although the Northern Territory's contribution to greenhouse gas emissions on a national and global scale is small, there is a need to take action to abate and reduce greenhouse gas emissions.

There is also a need for Governments and communities to adapt to climate change by managing risks and taking early action in order to reduce future costs to the community in the Northern Territory.

In view of the acknowledged seriousness of the problem of climate change, the Northern Territory Government should work closely with Local Government, all State Governments and the Australian Government to make firm commitments in setting emission targets.

Such commitments should ideally meet the current recommended target of the Garnaut Climate Change Review Report. It is important that any policy on Climate Change is consistent with the targets and goals set at a national and global level.

Harry Chan Avenue • GPO Box 84 Darwin NT 0801 Australia
Phone: 08 89300 300 • Fax: 08 89300 311 • Email: dcc@darwin.nt.gov.au • TTY: 08 89300 577
ABN 11 503 313 301

Whilst Australia as a whole and the Northern Territory in particular make a relatively small contribution to world energy use, we create large per capita emissions. It is therefore important for us as a significant per capita polluter, to play a leading role in planning for a sustainable future. Given the Northern Territory's emission profile, it is appropriate to focus reduction efforts on the key areas including urban design and planning, building efficiency, transport and savanna burning.

All opportunities to move towards renewable energy such as solar, wind, tidal and geothermal should be pursued. The research and development of new technologies should be encouraged and pursued as a matter of priority. With the development of LNG capability and facilities in the Northern Territory we strongly recommend that access to a proportion of gas which is brought on shore be reserved for local use. In addition, the development of CNG facilities in Darwin should also be considered.

A move towards eliminating reliance of fossil fuels needs to be considered through greater use of these renewable energy opportunities and the development of nuclear power should only be considered if these other options are not viable.

Improved public transport systems should become a high priority to reduce the level of emissions and demand on infrastructure. Significantly more effort and support is also required to reduce the emissions created by street lighting.

Climate change impact assessments should also form part of the framework for planning approvals, giving authorities the information needed to make informed decisions about energy efficiency for all developments.

The principle objective of the allocation of revenue made from carbon emission trading schemes should be to fund energy efficiency schemes and non-polluting renewable energy sources. Revenue received should also be directed to providing relief to low income households, so that they are not disadvantaged by higher energy and transport costs.

The current state of climate change science argues for urgency in dealing with both mitigation and adaptation. Action is required to ensure that public infrastructure, communities and their institutions are well prepared for climate change and related extreme events. The impacts of predicted sea level rise and changes in weather patterns needs to be assessed urgently and measures be put in place to accommodate and minimise their impacts. This needs to be a priority issue for all levels of government.

The need for water planning is of high importance and does not seem to be addressed in the discussion paper. The effects of increasing sea levels and the resulting increased salinity of ground water recourses has the potential to be have a considerable negative impact to the horticultural industry as well as Darwin's drinking water which is supplemented by ground water during the dry season.

The impacts on the natural environment are little understood by many in the general community. More research is required into the affects of climate change on native flora and fauna populations and their habitats as well as invasive species such as weeds and feral animals. The Northern Territory Government should ideally encourage partnership investment in research projects from industry as well as from its own budgets to increase the joint understand of the impacts of

climate change on the natural environment. This is particularly important to the Northern Territory as tourism and recreational activities based around the natural environment contribute significantly to the Northern Territory's economy and life style.

Climate change and sea level rise deliberations need to be considered in a framework of both Australian and internationally recognised scientific consensus.

References to such data sources should be provided in order to ensure confidence in reporting and decision-making. Unfortunately, there does not appear to be reference to the data used in the Discussion Paper so it is difficult to objectively assess matters in a national context.

Darwin City Council is committed to addressing climate change and has developed a Green House Action Plan which it commends to you for consideration in response to your Discussion Paper on Northern Territory Climate Change Issues.

In addition, Darwin City Council is keen to enter into a partnership with the Northern Territory Government in order to address Climate Change issues affecting the Darwin community.

Council is in the process of contacting the Minister for National Resources, Environment & Heritage in order to initiate the development of this partnership.

We would appreciate further advice as to the outcome of your deliberations and decisions from the response and submissions to your Discussion Paper and thank you for the opportunity to comment.

Yours sincerely,

BRENDAN DOWD
DIRECTOR TECHNICAL SERVICES

REGISTRATIONS NOW OPEN

A focus on practical strategies and solutions

Early Bird closes 4th July 2008 - not too far away!

PLAN TO ATTEND THIS IMPORTANT EVENT

CONFERENCE DATES:
3-5 August 2008

LOCATION:
Coffs Harbour NSW
Novotel Pacific Bay Resort

TARGET AUDIENCE:
Engineers, Technical Staff, Consultants, Planners, CEO's, Elected Members

Institute of Public Works Engineering Australia

In association with

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Coffs Harbour City Council

Responding to Sea Level Rise

ENGINEERING PRACTICAL CLIMATE CHANGE SOLUTIONS

Australian Coastal & Tidal Councils:

IPWEA National Conference on Climate Change Response

Responding to Sea Level Rise

One of the key issues for coastal & tidal councils is the impact of sea level rise over the long term, and more immediately the impact of the combination of storm surges and high tides on a council's coastal infrastructure.

This conference focuses on coastal & tidal council engineering staff and consultants who have been involved in the development of coastal and estuarine management response to sea level rise.

Extent | Impacts | Risk | Adaptation | Strategies | Response Land Use Planning | Storm Tides | Community | Engagement | Emergency Management | and more...

The conference will provide the opportunity to bring together people who are facing the same climate change challenges. The aim is to share ideas and to learn how other council staff and consultants are innovating and developing adaptation responses to sea level rise.

Early Bird closes Friday 4th July 2008.

Visit the IPWEA website: **www.ipwea.org.au/coffs2008** for further information, outline program, and to download **the registration brochure.**

SPONSORS & EXHIBITORS: An opportunity to promote your products & services to key public works professionals on a targeted national basis. For further information, contact: Ross Moody, Executive Officer IPWEA National email: rmoody@ipwea.org.au phone: 0417 955 394

CONFERENCE PROGRAM

Conference Organisers reserve the right to alter the program or provide replacement speakers

Sunday 3rd August 2008

2 00 - 6 pm	**Registration** Foyer of the Novotel Pacific Bay Resort Corner Pacific Highway & Bay drive, Coffs Harbour NSW
3 00 – 5 pm	**Coach tour of Coffs Harbour Sewerage and Water**
6 00 – 8 pm	**Welcome Reception** Canapés & Refreshments on Charlies Deck overlooking the Lagoon – Music by pianist Roy Mitchell Master of Ceremonies – Graeme Singleton Welcome to the City – Mayor of Coffs Harbour
	Dinner – Conference participants may make their own arrangements

Monday 4th August 2008

8-00 – 9.00am	**Registration** Foyer of The Conference Centre at Novotel Pacific Bay Resort	
	The Reef Room	
9.00 – 9.05	**Welcome** John Truman, National Vice President, IPWEA	
9.05 – 9.20	**Setting the Scene** Professor John Martin, Director of the Centre for Sustainable Regional Communities La Trobe University, Bendigo Campus	
9.20 – 9.30	**Opening of Conference**	
9.30 – 9.55	*First Keynote* **A Special Speaker - To be advised**	
10.00 –10.25	*Second Keynote* **Vulnerability of the Australian Coast to Climate Change** Professor Colin Woodroffe, University of Wollongong	
10.30– 10.55	**MORNING TEA**	
Concurrent Sessions	**Reef Room**	**Jetty Room**
	Extent of Sea Level Rise Setting the Scene	**Impacts & Risk Assessment I: Planning Responses**
11.00 –11.25	**Estimating Changes in Sea Level Extremes under conditions of Rising Sea Level** John Hunter Antarctic Climate & Ecosystems CRC, TAS	**Three Pass Assessment Approach to Coastal Risk Management** Chris Sharples, University of Tasmania, TAS
11.30 –11.55	**Anuga The Free Ocean Impact Model** Rudy Van Drie Balance Research and Design, NSW	**Modelling Coastal Processes & Hazards to Assess Sea Level Rise Impacts** James Carley, Water Research Laboratory UNSW, NSW
12.00 – 12.25	**Are there Less Obvious Potential Climate Change Responses** Dr Ian Joliffe, Jemma Sargent, Mary-Jane Piggott, Dr Rainer Berg, GHD, NSW	**Establishing Triggers for Adaptive Response to Climate Change** Clive Attwater SGS Economics & Planning, TAS
12.30 – 1.25	**LUNCH - Light lunch provided**	

Monday 4th August 2008, continued

Concurrent Sessions	Reef Room	Jetty Room
	Impacts & Risk Assessment II: Council Responses	**Impacts & Risk Assessment III: Site & Locale Responses**
1.30 – 1.55pm	**Responding to Assessed Climate Impacts: Implications for Bayside Planning & City Resilience** Lalitha Ramachandran, Kate Nagato City of Port Phillip, VIC	**Sea Level Rise Implications & Adaptation for South Arm Secondary Road, Hobart** Matt Blacka, James Carley, Dion Lester, Brian Williams Water Research Laboratory UNSW, NSW, Pitt & Sherry, TAS
2.00 – 2.25	**Port Adelaide Seawater & Stormwater Flood Risk** Russell King, Drew Jacobi City of Port Adelaide Enfield, SA Tonkin Consulting, SA	**Sea Level Rise & Climate Change Impacts for Planning a New Hospital** James Carley, Matt Blacka, Ron Cox, James McIntosh, Jane McArthur, Water Research Laboratory UNSW, NSW
2.30 – 2.55	**Integrated Assessment of Climate Change in Western Port Region, Victoria** Bruce Douglas Mornington Peninsula Shire Council, VIC	**Review of Land Development Policy to Manage Impacts of Climate Change in Manukau City** Mohammed Hassan, Zheng Qian , Doug Ramsay Manukau City Council, NZ
3.00 – 3.25	**AFTERNOON TEA**	
Concurrent Sessions	**Reef Room**	**Jetty Room**
	Adaptation Strategies I	**Wider Impacts & Responses**
3.30 – 3.55	**Choosing from Adaptation Options: More than a Short Term Cost Benefit Approach** Clive Attwater, Ellen Witte SGS Economics & Planning, TAS	**Anticipated Response of Coastal Lagoons to Sea Level Rise** Dr Philip Haines, Dr Bruce Thom BMT WBM, NSW
4.00 – 4.25	**Planning Controls to Manage Increased Tidal Inundation of Estuarine Foreshore Development** Peter Sheath Gosford City Council, NSW	**Balancing the Risks across your Total Business: Is Sea Level Rise the Only Risk you should be Addressing?** Roger Byrne, Brenton Marshall GHD, VIC
4.30 – 4.55	**The Changing Coast: Providing Room for Natural Adjustments** Chris Sharples, Clive Attwater University of Tasmania, TAS	**A Far South Coast Story** Mark Canaider, Derek van Bracht, David Basil Bega Valley Shire Council, NSW
6.30 – 7.00	**Pre-Dinner Drinks in the Bay Marquee**	
7.00 – 10.30	**Dinner in the Bay Marquee - proudly sponsored by GHD** Master of Ceremonies – Graeme Singleton Welcome Address - Phillip Pigram, GHD Coffs Harbour Office Manager Music & Entertainment	

Tuesday 5th August 2008

Concurrent Sessions	Reef Room	Jetty Room
	Adaptation Strategies II	**Planning Land Use**
8.30 – 9.00am	**Floodplain Management: Adapting for Sea level Rise** Richard Dewar, Duncan McLuckie WMAwater Consulting Engineers, NSW NSW Dept of Environment & Climate Change, NSW	**Climate Change Driving a New Social Divide** Ellen Witte, Clive Attwater SGS Economics & Planning, TAS
9.00 – 9.25	**Managing Sea Level Rise & Climate Change** Bruce Harper Systems Engineering Australia, QLD	**That Sinking Feeling: A Town Planning Response to Sea Level Rise** Tarnya Fitzgibbon McCullough Robertson Lawyers, QLD
9.30 – 9.55	**Using Pittwater's Floodplain Management Strategy as the Key to Adaptation Strategies for Climate** Sue Ribbons Pittwater Council, NSW	**Planning Schemes & Legal Issues: Adjusting the Instruments to Changing Conditions** Paul Howorth, Clive Attwater SGS Economics & Planning, ACT

Tuesday 5th August 2008, continued

10.00– 10.25	**MORNING TEA**	
Concurrent Sessions	**Reef Room**	**Jetty Room**
	Community Impact & Engagement	**Storm Tide & Emergency Management**
10.30 – 10.55	**Bearing the Cost: Setting Price Signals & Co st Sharing to Ensure a Soft Landing** Clive Attwater, Ellen Witte SGS Economics & Planning, TAS	**Caloundra City Storm Tide Management** Megan Gould, Gilda s Colleter, Michael Erpf Connell Wagner, QLD Sunshine Coas t Regional Council, QLD
11.00 – 11.25	**Decision Making in Lo cal Government** Dr Petra Behrens, Peter Gibson Connell Wagner, QLD	**Storm Tide Risk Assessment s in Tropical & Sub Tropical Areas: Climate Change Impacts & Emergency Management Needs** Ross Fryar, Bruce Harper, I Botev, P Priebbenow, GHD QLD
11.30 – 11.55	**Communications: Critical to Achieving Public Support for Adaptation** Ellen Witte, Clive Attwater SGS Economics & Planning, TAS	**Climate Change Strategy for Gold Coast City Council** Khondker Rahman, Hamid Mir fenderesk Connell Wagner, QLD Gold Coast City Council, QLD
12.00 – 12.55	**LUNCH – Light lunch provided**	
	The Reef Room	
1.00 – 1.30pm	**Panel Session / Keynote** To be advised	
1.30 – 2.20	**Future Needs & Directions: Delegates Forum** Professor John Martin, Director CSRC La Trobe Uni versity, Bendigo Campus	
2.20 - 2.30	**Conference Close** Chris Champi on, Chief Executive Officer, IPWEA Nati onal	
2.30pm	**Delegates Depart**	

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2008 IPWEA National Conference on Climate Change Response

Novotel Pacific Bay Resort in Coffs Harbour NSW

3RD, 4TH, 5TH August 2008

Conference Registration

www.ipwea.org.au/coffs2008

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1 Personal details of delegate.

Title..............First Name.. Surname..

Name as you would like it to appear on name tag ....

Organisation...

Position..

Postal Address..

Suburb/Town ....State............................Postcode........................

Country (if not AU)...Email...

Work Telephone...Mobile...

☐ I do not want my details to be included in the delegate's list

2 Accompanying Person
If you are purchasing a registration for an accompanying person, please provide their name below:

First Name ....Surname ....

3 Special requirements (Please indicate any specific dietary, medical or other requirements).
Delegate...
Accompanying person..

4 Optional – Next of Kin details In case of emergency.
Name ....Contact phone number ....

5 Accommodation
Please refer to the Pacific Bay accommodation form on the Conference website www.ipwea.org.au/coffs2008.
Guests are to make their own arrangements and are responsible for their own accounts.

Or go to www.pacificbayresort.com.au

2008 IPWEA National Conference on Climate Change Response

6 Type of registration. Early bird – Registration and Payment to be received by 4th July 08
Registrations should be submitted by Friday 25th July 2008

Registration Type	Number attending	**Early bird** By 4 July	**Standard** After 4 July	**Total**
Delegate Name:				
Full Conference package - Welcome Reception, Conference Dinner and Day 1 and 2 of Conference – includes morning tea, lunch and afternoon tea.		$795-	$895-	
Technical Tour Sunday afternoon (3.00pm – 5.00pm)		$40-	$40-	
Accompanying partner tickets – Welcome Reception and Conference Dinner		$150-	$150-	
Additional Guests				
Welcome Reception - Additional tickets		$50-	$50-	
Conference Dinner – Additional tickets		$110-	$110-	
* Please advise of any dietary requirements			SUB TOTAL	
			PLUS 10% GST	
			TOTAL	

7 In order to assist with transport and catering, please indicate your intention to attend (**transfer cost to above table for additional tickets and technical tour)**

	Delegate		**Accomp. Partner** (where registered)		**Additional guests**	**No. required**
Sunday Technical Tour (3.00pm – 5.00pm)	☐ Yes	☐ No	☐ Yes	☐ No	$40-	
Sunday Welcome Function	☐ Yes	☐ No	☐ Yes	☐ No	$50-	
Monday Conference Day 1	☐ Yes	☐ No				
Monday Conference Dinner	☐ Yes	☐ No	☐ Yes	☐ No	$110-	
Tuesday Conference Day 2	☐ Yes	☐ No				
					Transfer $ amounts to above table at Item **6**.	

8 Payment Method:

☐ **Direct bank transfer** to: Commonwealth Bank – Account Name: IPWEA Limited
BSB: 062-032 Account No: 2800-9626

☐ **Credit Card payment**: ☐ Bank Card ☐ MasterCard ☐ Visa

Name on Card..Card No..

Expiry Date............................/...................................Signature..

☐ **Cheque, money order or bank draft** payment enclosed
Please make cheques payable to IPWEA National

Cancellation Policy – All cancellations must be made in writing to Lita Somogyi. Cancellations after 4 July before 25 July 50% refund. No refunds for cancellations after 25 July. Substitute names accepted. No refunds issued until after conference.

RETURN TO: Institute of Public Works Engineering Australia, Level 12, 447 Kent Street, SYDNEY NSW 2000
Fax: 02 9283 5255 www.ipwea.org.au/coffs2008

For enquiries: Please contact Lita Somogyi, E: national@ipwea.org.au, Tel: 02 8267 3001

Lake Macquarie
City Council

Planning Levels and Other Adaptation Responses to Sea Level Rise and Climate Change – Fact Sheet

At its meeting of 12 May 2008, Council considered and approved a report that recommends adopting, for purposes of preparedness and future planning, a sea level rise scenario that predicts a rise of 0.91 metres by 2100. The report also recommends that floor height requirements in flood-prone areas be adjusted to meet this predicted rise. The report and recommendations (see below) are now open for public comment and submissions before Council makes its final consideration in July. The exhibition period closes on ***Friday June 20 at 5pm.***

What did the report recommend?

Council:

A. Publicly exhibit a proposal to adopt the NSW Department of Environment and Climate Change's projected upper sea level rise figure for the year 2100 of 0.91m as the basis for Council staff to proceed with risk assessment, policy development, and planning and development decisions.

B. Supports the application of the principles outlined in A above for the purposes of preparedness for sea level rise, which includes risk assessment, community awareness, and policy and development decisions.

C. Undertakes community consultation activities, for a period of one month, including liaison with relevant government agencies and adjoining councils, with regard to A above and receives a further report on the outcomes from the community consultation.

D. Reviews the above figures if and when the NSW Government recommends a level under its planning policies and manuals, such as the Coastline Management Manual, and/or in the light of new scientific evidence.

E. Continues to monitor, review, and manage the risks associated with climate change relating to local government functions.

F. Acts to reduce greenhouse gas emissions through ongoing climate change mitigation strategies.

G. Amends Development Control Plan No.1, in particular Sections 2.1.7 Flood Management and 2.1.8 Development on Flood Prone Land at Dora Creek, and other relevant sections, to reflect the above recommendations.

H. Commences a comprehensive review of other Council statutory and regulatory planning policies, plans, and procedures to reflect the above recommendations.

How was the prediction for sea level rise of 0.91 metres by 2100 calculated?

Council has decided on this figure based on the best available scientific information and by choosing to "err on the side of reasonable caution." The calculation assumes a high greenhouse gas emissions scenario.

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007) – global average sea level rise (ignoring ice melt) - high emissions scenario	0.59 metres
Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007) – allowance for ice melt uncertainty	0.20 metres
CSIRO Technical Report (2007) – calculation for local variation on IPCC global average sea level rise	0.12 metres
Accumulated level	**0.91 metres**

Why does Council have to adopt a prediction for sea level rise?

Council is responsible for planning future development in Lake Macquarie, for managing the natural environment, and for the wellbeing of residents. Planning and development decisions taken now will still be "on the ground" in 50 to 100 years. This places a duty of care on Council to plan for the future based on the best available information. The proposed rate for sea level rise allows Councillors, Council staff, and the community to develop policies, carry out more detailed studies, and make planning and development decisions that are suitable for the changed conditions. Legal advice indicates that Council may be liable for future damages if it does not properly consider the impact of sea level rise and other climate induced changes in its planning and policy decisions.

Will Lake Macquarie rise by the same level as the Pacific Ocean?

The average level of the Lake is currently about 0.1 metres higher than the Pacific Ocean. While it is expected the Lake will rise roughly in line with sea level rise, the pumping effect of tides through Swansea Channel and other localised factors mean there will be local variations. Council will use the predicted sea level rise of 0.91 metres by 2100 as the basis for further research and modelling to more accurately predict how the Lake will respond, and predict the impacts on the Lake foreshore.

What are the risks from sea level rise?

The table below, prepared by the Sydney Coastal Councils Group, sets out the main impacts from sea level rise on the coastline and along estuarine foreshores. In general, the impacts on estuaries will be less severe than on the coast.

Impact	**Description**
Coastal erosion, retreat, and storm	▪ Increased rates of erosion ▪ Beach realignment ▪ Increased flooding ▪ Saline water intrusion further into creeks and groundwater ▪ Increased storm surges and long term inundation

Ecological Impacts	▪ Threats to ecological communities unable to adapt to change in salinity levels ▪ Changes in wetland and mangrove distribution ▪ Other flora and fauna impacts
Damage to infrastructure	▪ Damage to public and private infrastructure including roads, bridges, houses and other buildings ▪ Damage to utilities including water and electricity
Public health	▪ Morbidity and mortality associated with adaptation to sea-level rise e.g. community wellbeing
Economic	▪ Increasing insurance premiums ▪ Investment in climate change mitigation measures ▪ Increased depreciation of land and building values ▪ Loss of tourism, recreation and transportation functions

What will Council do to address these risks?

One of the main reasons for adopting a sea level rise prediction for Lake Macquarie is to allow Council to make a considered assessment of risk and response to risk. Except for the risk from increased flood heights (see below), there are as yet no specific proposals for changes in Council's planning and development processes. However, these issues will be addressed over the next few years, once Council adopts a sea level rise prediction.

Hazard Management Options Suggested by Coastline Management Manual	
Category	**Management Option Examples**
Environmental Planning	• Restrictive Zonings • Planned Retreat • Voluntary Purchase
Development Control Conditions	• Building Setbacks • Raised floor levels • Relocatable Buildings • Planned Retreat
Coastal Dune Management	• Dune Reconstruction and revegetation • Dune Protection and/or Maintenance
Protective Works	• Seawalls • Groynes • Beach Nourishment • Offshore Breakwaters

Having a well-informed and prepared community is an essential part of Council's adaptation response to climate change and sea level rise. Your interest and involvement early in this process will assist the community's and Council's preparedness and response.

Will sea level rise make flooding worse?

If sea levels increase, and the Lake rises similarly, then Lake flood levels will also rise. Currently floor levels in low-lying and flood prone areas are set at 0.50 metres above the calculated 100-year flood level – 1.88 metres AHD for most areas around the Lake foreshore. If Council assumes an average house has a life of 50 years before it is renovated or re-built then, based on the proposed sea level rise scenario, flood levels will be up to 0.49 metres higher by the time the house is due for renewal. It is proposed that this amount be added to current floor height requirements in low-lying areas, making the floor height requirement for habitable rooms in new houses 2.37 metres AHD.

As Floodplain Management Plans and other detailed modelling are developed for flood-prone areas around the Lake, and along creeks and watercourse, this adjusted level will be "fine tuned" to fit with variations caused by topography and other local features.

What is the difference between inundation and flooding?

Some low-lying areas along the coast and around the Lake foreshore may be inundated as sea levels rise. This means they are **permanently** covered by rising water. Other areas may be affected by increased flood levels, where water covers the area **temporarily** due to waves, high rainfall, or storm surge.

What about other changes due to climate change, such as increased storm intensity?

Scientists predict that, as a result of climate change, the east coast of Australia is likely to experience more frequent storms, more intense storms, and more intense rainfall. Added to increase in sea level, this will make the impact of floods and storms more severe. Council will use the proposed sea level rise scenario as a base to estimate the increase in risk from these hazards, and will incorporate them in Council's planning controls and emergency response plans. Council and other agencies are beginning to address other predicted climate change impacts, not directly related to sea level rise, such as heat waves, environmental health issues, droughts, and wind storms.

What if the scientists have got it wrong?

There is widespread agreement among scientists that human production of greenhouse gases is causing an increase in global temperature. This, in turn, is leading to a rise in sea level through thermal expansion of the oceans and from ice melt. These changes are measurable and documented. There is more uncertainty about how quickly this is happening, how far it will go, and whether we will be able to substantially reduce our production of greenhouse gases over the next 50 years.

Council has adopted a "high emissions" scenario as it fits most closely with the observable changes in temperature and sea level. It is easier to "relax" from an over-pessimistic prediction than it is to "catch up" with an over-optimistic prediction. Council will regularly review the scientific predictions and the policies developed by Sate and Commonwealth Governments, and adjust the predicted levels in Lake Macquarie in the light of new information.

Will the recommendations in Council's report affect what I can and can't do on my property?

The only specific recommendation in this report that may have an effect on properties or new developments is the proposal to raise the level of floor heights in flood prone areas (see above). Council may introduce other planning and development changes to cope with sea level rise and other climate change impacts, but these will be the subject of future studies and proposals. Any major changes will include a process of community input and consultation before being decided by Council. Some of the issues and options to be considered are outlined in the table (above) under the heading **"What will Council do to address these risks?"**

How can I obtain further information?

Just click on the links below to access the relevant reports:

Report to Lake Macquarie City Council (12 May 2008) –www.lakemac.com.au

CSIRO Technical Report (2007) - http://www.climatechangeinaustralia.gov.au/

IPCC Fourth Assessment Report (2007) - http://www.ipcc-wg2.org/

Coastal Councils and Planning for Climate Change (February 2008) - http://www.sydneycoastalcouncils.com.au/SydneyCoastalCouncilsGroupInc.NSWAustralia.htm

How can I make a submission or comment?

Council will receive submissions on the report and its recommendations up until **5pm Friday 20** June by:

Email: council@lakemac.nsw.gov.au

OR

Writing: The General Manager
Lake Macquarie City Council
Box 1906
HUNTER REGION MAIL CENTRE 2310

OR Hand-delivered to the Customer Service Counter at 126-138 Main Road, Speers Point.

Please mark all submissions on the envelope or in the subject line "Sea Level Rise Report"

Sea Level Rise – A New Zealand Context

Iain Dawe, Greater Wellington Regional Council
iain.dawe@gw.govt.nz

1.0 Introduction

It is estimated that 20% of the global human population lives in coastal cities and of these 100 million people live within 1.0 m or less above mean sea level. Most of New Zealand's population lives in coastally located cities and towns. Historically, permanent Maori settlements were almost exclusively in coastal areas because of access to kaimoana and ease of coastal travel on waka. European immigrants found harbours ideal places to settle because they afforded sheltered ports and access to sea transportation networks. Coastal areas are also appreciated as attractive places to live and recreate. Over the past 150 years holiday resorts and communities have developed in low lying areas close to the shoreline in many places around the New Zealand coast. However, these developments are vulnerable to coastal hazard events and sea level rise.

Sea level rise is a major effect stemming directly from changes in the global climate. In the past few years there has been a dramatic awakening in the public consciousness of the very real changes that are occurring in our local climate. This increasing awareness has seeped through to Central and Local Government, which is now starting to take the issue seriously. In the past six months Central Government has released a number of policy discussion documents on climate change issues facing New Zealand. Government is looking for significant input from the local government sector, that is also expected to be heavily involved in the implementation of these policies.

Coastlines form at the interface between oceans and terrestrial land. They are composed from a variety of rock and sediment types and present a wide range of geomorphologies from sheltered harbours, inlets and estuaries, to bold rocky and cliffed coasts, to long sandy dune coasts and exposed oceanic gravel beaches. They are extremely dynamic places and when left naturally, they have the ability to absorb vast amounts of wave and tide energy to which they are subjected ceaselessly day after day.

There are a number of important energy and sediment input agents that drive changes in the coastal system. At a first order level, geologic and climatic variables control sea levels, wind, waves and currents that in turn control beach geomorphology and sediment supply and transport. Sediments nourish a beach allow it to maintain its position against the ocean and its battering ram of waves. When there is ample sediment transported in a beach system, a beach will prograde or grow seaward. However, when sediment supplies to a beach are interrupted or naturally limited, a coast will erode. As discussed, sediment supply and transport is controlled by a number of environmental variables that are easily disrupted by human or natural activity. When we construct houses in sand dunes, construct causeways across inlets, reclaim land for development and roading, we interfere with the natural beach system and the flow of sediments that nourish a coastline. In doing so we place our communities, infrastructure, homes, businesses and assets at risk from coastal hazard events. Increasingly, sea level rise will add to this risk.

This paper discusses the history of sea level rise, the current state of knowledge, what rises might be expected in the future. It outlines the environmental processes that control sea level and the impacts of sea level rise on coastal margins and communities. The paper finishes with a summary of the statutory tools and planning options that can be used to manage sea level rise in New Zealand.

2.0 Sea Level Controls

The level of the sea surface is controlled by a complex inter-relation of short, medium and long term variables. Sea level at a given coastal location is a relative measure made up of variations in both the oceanic and terrestrial environment. The actual water volume in the global ocean is referred to as global eustatic sea level, but this is only one component of what makes up local observed sea level. In the long term, local isostatic and tectonic adjustments can alter the land relative to the sea. In the medium term, annual and inter-decadal fluctuations in the sea surface can result from large scale tide and climate cycles. In the short term, there are monthly and daily fluctuations in the sea surface from lunar tide cycles and weather related effects.

2.1 Long Term Sea Level Controls

On a geological timescale, sea levels have fluctuated dramatically on a scale of 10s -100s of metres in response to long term variations in the global climate. Cold periods or ice ages are associated with lower sea levels, whilst warmer periods are associated with higher sea levels. Since the height of the last ice age, about 20 000 years ago, global mean sea level has risen by more than 100 m due to melting ice sheets, causing a marine transgression. Most the rise occurred between 12 000-6000 B.P., with a period of quasi-stabilisation since 4000 B.P. In the past 1000 years, sea level is estimated to have been rising at a rate of around 0.2 mm/yr, although there are many regional variations to this figure.

It is important to distinguish between these eustatic changes and adjustments to the land surface that cause relative local changes in sea level. There are two major processes responsible for this. The first is known as glacial isostatic adjustment or isostatic uplift. This occurs because large ice sheets, such as those that covered northern Europe, Canada and southern New Zealand and which currently exist in Greenland and Antarctica, exert massive force on the underlying land surface, causing it to be depressed. When an ice sheet melts, the land surface rebounds vertically as it distresses with the loss of overlying mass. This causes a local relative drop in sea level as the area that was covered in ice effectively rises up and out of the sea. An interesting example of this comes from Norway where archaeological investigations have revealed old fishing villages stranded high and dry above water level due to isostatic uplift over the past 10 000 years. Much of the southern part of New Zealand is experiencing isostatic uplift in the order of 0.5 mm/yr.

The second major process responsible for causing changes to the land surface are tectonic forces. These can cause long term increases or drops in relative sea through uplifting or subduction of the land surface. Much of the New Zealand coast is subject to tectonic adjustment. This process can occur gradually or catastrophically. For example, in the Wairarapa earthquake in 1855, one of the largest earthquakes in recent New Zealand history, land was uplifted 1-2 m around Wellington Harbour. This land has now been used to construct roads, the CBD and the airport. The 1931 Hawkes Bay earthquake caused uplift of 1.8 m at Westshore, Napier and the Bay of Plenty earthquake in 1987 caused about 0.4 m of subsidence along the Rangitaiki coast.

2.2 Medium Term Sea Level Controls

Annual and inter-decadal climatic oscillations affect sea levels around the New Zealand coast. When these fluctuations are factored into the local sea level measurement they produce what is referred to as the mean level of the sea (MLOS).

There are three main climatic effects:

- Annual seasonal heating and cooling of the sea surface from solar radiation. This occurs because water expands as it warms and contracts as it cools. The sea surface is typically around 0.04 m higher in the summer and any given year the variation can be as much as ±0.08 m.
- El Nino/La Nina cycles (Southern Oscillation) that can alter sea levels by up to ±0.12 m.
- The Interdecadal Pacific Oscillation (IPO) that occurs on a 20-30 year cycle and can alter sea levels by up to ±0.05 m.

The combination of these factors means that local sea level can vary annually by as much as ±0.25 m from the long term mean.

Tides vary in height due to the position and distance of the moon as it orbits earth that operate on a daily, fortnightly and monthly cycle. Tides are generally highest (and lowest) on the new and full moon - known as the spring tides. The average elevation of these tides above a chart datum is referred to as the mean high water springs. There is a 18.6 year tide cycle that produces what is known as the highest astronomical tide, sometimes called a king tide. King tides have been forecast to occur for parts of the New Zealand coast in April 2012. Tide height is strongly linked to the occurrence of coastal flooding and inundation during storm events.

2.3 Short Term Sea Level Controls

Storm surge is a short term elevation of the local sea level due to meteorological conditions and is due to three main factors; wind set-up, wave set-up and barometric lift. Wind and wave set-up occurs when strong winds and large waves force water onshore causing an elevation of water levels at the shoreline. Barometric lift occurs because, below air pressure of 1014 hPa, the sea surface rises *ca.* 1.0 cm for every 1.0 hPa drop in pressure. In a depression with air pressures of 980-985 at the centre, this equates to a localised elevation of 0.30-0.35 m.

In the New Zealand region storm surge is most commonly associated with southerly storms and ex-tropical cyclones that bring with them strong winds, large waves and low air pressure. Together these effects can cause a significant rise in local water level. The Wahine storm (an ex-tropical cyclone) and the southerly storms of 1976 & 1992 all produced storm surges in the order of 0.50-0.80 m above mean sea level. Storm surges have the capacity to cause significant damage, especially when they occur on top of high tides.

These medium and short term events will all continue to occur on top of a long term rise in global eustatic sea levels.

3.0 Sea Level Rise in the Past Century

Measurements of a recent rise in sea level come from historical tide gauge data. Tide gauges in harbours and ports around the world, record fluctuations in the sea surface on an hourly, daily, monthly and annual basis. The data collected from these gauges is then used to provide information about the tidal range and to define levels such as high and low water springs and mean water level. Over longer periods these data can reveal important inter-annual and inter-decadal variations in the tides and the sea surface. The oldest records date back to the mid 18th Century at the start of the Industrial Revolution. Reliable long term tide records have been collected continuously at ports around the world since the 1870s, and now form an invaluable record for examining longer term changes in the level of the sea.

Analysis of tide gauge records from around the world shows that over the last 150 years, sea level has risen at an average rate of 1.0-2.0 mm/yr or a total of 0.15-0.30 m. This is a significantly faster rate that at any stage in the past 1000 years. Measurements from the 20th Century alone, indicate that the rise has been in the upper end of this average at 1.7 ±0.2 mm/yr. Over the period 1961-2003 the rate was 1.8 mm/yr with a range of 1.3-2.3 mm/yr. In the decade from 1993 to 2003 the rate was faster still, rising at around 3.1 mm/yr with a range of 2.4-3.8 mm/yr. It is unclear whether this reflects inter-decadal variability or an increase in the long term trend. Nevertheless, there is a high level of confidence that the rate increased from the 19th to the 20th Century.

3.1 Sea Level Rise in New Zealand

Sea levels have been recorded on tide gauges at ports around New Zealand for over 100 years. The earliest records come from Wellington Harbour and date back to 1891, but the longest and most reliable record comes from Auckland where there has been near continuous measurements since 1899. The first study of these records was conducted in 1988 by Professor John Hannah who is now head of the University of Otago Survey School. After correcting for isostatic, tectonic and inter-decadal variations, Hannah showed that since measurements began, all the records display a gradual linear increase in the height of the sea surface around New Zealand at rate of 1.7 mm/yr with a range of 1.30-2.08 mm/yr. Hannah recently updated this work to 2001 and included some older records uncovered in archives that have extended the historical record. The trends around New Zealand remain almost the same at 1.6 ±0.2 mm/yr. This is in line with measured global sea level rise. The measured increases in sea level rise from the four ports examined in the study can be seen in Table 1.

Table 1: Sea level as measured from tide gauges at four ports around New Zealand 1891-2001.

City	Auckland	Wellington	Christchurch	Dunedin	*Average*
Rate (mm/yr)	1.30	1.78	2.08	0.94	***1.60***
Rise from 1900 (m)	0.14	0.19	0.22	0.10	***0.16***

4.0 What Is Causing Sea Level Rise?

Just as climate changes in the past were responsible for causing fluctuations in sea level, so too is global warming or 'climate change' directly responsible for causing the sea level rise we currently observe. The two biggest contributing factors to eustatic sea level rise are thermal expansion of the ocean and ice melt. Both these processes are being driven by an increase in the mean global surface temperature. The mean global temperature has increased by 0.74 °C in the past century and the warming over the past 50 years is double that over the previous 100 years. New Zeaaland has experienced a 0.4 °C warming since 1950.

Observations since 1961 show that the average temperature of the ocean has increased globally, and not just at the surface. Temperature increases have been detected at depths of over 3000 m. Water acts like a thermal sink and is very effective at absorbing and retaining heat. It is thought that the ocean has absorbed more than 80% of the temperature increases experienced since 1850. The side effect of this is that it causes the seawater to expand, effectively increasing the volume of the ocean and contributing to eustatic sea level rise. The relative contributions of the various inputs to sea level rise can be seen in Table 2.

Glaciers, icecaps and snow packs have receded on average in both the northern and southern hemisphere over the past 50 years, contributing to sea level rise. Large contributions have come from the Greenland and Antarctic ice sheets that have each contributed 0.21 mm/yr since 1993. New Zealand has lost a quarter of its ice mass since 1950.

Table 2: Contributing factors of sea level rise.

Rate of sea level rise (mm/yr)	**1961-2003**	**1993-2003**
Contributing Factor		
Thermal Expansion	0.42	1.60
Ice Melt (glaciers/ice sheets)	0.69	1.19
Other contributions	0.70	0.30
Total Observed	**1.80**	**3.10**

5.0 Future Projections

Sea level was 4-6 m higher during the last major inter-glacial or warm period about 125 000 years ago. At this time research indicates that global temperatures were 3-5 °C higher than at present. Future projections for global temperature increases are within the range 1.8-4.0 °C. Even if all the drivers of climate change were held constant at 2000 levels, there will be continued warming of 0.1 °C per decade for the next 20-30 years, due to the slow thermal response times of the oceans. In other words, we are locked into a certain amount of climate change and sea level rise for the next few decades. However, most realistic projections are for a warming of 0.2 °C for at least the next 25 years. The first temperature projections published by the IPCC in 1990, were for a warming of

0.15-0.30 °C per decade for the period 1990-2005. Measured values over this period indicate that the warming has been 0.2 °C, adding confidence to future projections. Global mean temperatures are higher now than they have been in the past 1300 years. Taking this into consideration, a range of scenarios were used in the IPCC 4AR to project sea level rise. They all point to continued sea level rise over the next century and indicate that we can expect sea levels to increase in the range 0.18-0.59 m by 2100.

Recently, satellites using radar altimetry methods have provided high quality measurements with nearly global coverage since 1993. These satellites can provide measurements of global sea level to an accuracy of several millimetres every 10 days. Data from these satellites indicate that sea level has been rising at a faster rate of 3.0 mm/yr, than the mean rate estimated for the 20th Century. This is higher than in all previous decades measured. For reasons that are unclear, the rise has been greater at the coastal margins, than in the deep ocean. The evidence indicates that there has been a small but significant acceleration over the period 1870-2004 in the order of 0.013 mm yr^{-2}. If this acceleration remains constant, then the rise in sea level expected by 2100 will be in the order of 0.28-0.34 m, which is within range of the latest estimates published in the IPCC Fourth Assessment Report (4AR).

6.0 Impacts of Sea Level Rise

There are a range of impacts that a rising sea level has on the coastal margin, but essentially they can be categorised under two main headings; erosion and inundation. The way in which a coastline responds depends upon its geomorphology and constituent materials (sand/gravel/rock) and its exposure to tide and wave and current conditions.

The most serious physical impacts of sea level rise on coastal areas will be:

- Coastal inundation causing landward movement of estuaries, inlets, lagoons and wetlands.
- Coastal erosion and shoreline changes due to alteration of sediment transport systems
- Increased vulnerability to coastal storm damage
- Increased coastal flooding on extreme high tides, during high wave conditions and storm surge events
- Increased difficulty in river drainage, especially during flood events that may increase flood duration around low lying delta areas
- Possibility of enhanced estuary infilling through increased sediment loads from flood events and runoff during intense rain storm events
- Increased tidal prisms of tidal inlets, estuaries and lagoons leading to possible scouring and erosion around inlet entrances and adjacent beaches
- Salt water intrusion into coastal aquifers and increased saline penetration along rivers

6.1 Flooding and Inundation

The most direct impact of sea level rise is flooding and inundation of low lying coastal areas, especially around estuaries, inlets and river mouths. A rising sea level allows more frequent coastal flooding events from storms, storm surges and extreme high tides because it raises the background height water level on which these processes occur. Sea level rise effectively increases the probability or recurrence interval of a given flooding event. Higher sea levels allow wave run-up and water levels to reach further inland. Large waves, extreme high tides and storm surge events may all cause more frequent flooding.

Eventually, the flooding events may become so frequent, that it leads to permanent inundation of very low areas of the coast. This is a slow and gradual process, that starts with increasingly frequent flood events from high tides and storm events. Over time the flooding events become more common as the tide range advances inland until it reclaims a low lying area of land that becomes part of the inter-tidal zone. This is most likely to occur around the margins of estuaries and river mouths.

6.2 Erosion

Inundation on its own does not cause erosion, rather it is wave and current activity that removes sediment from a beach that causes erosion. High sea levels allow waves to run higher up a beach and scour sediment from the backshore area. The way in which a beach responds to this depends on its constituent materials, its geomorphology and its exposure to wave and current activity.

6.2.1 Prograding Shores

Sea level rise will occur on top of the range of natural processes that already occur in a beach. A beach may have one of three states. It may be prograding or growing, it may be actively eroding, or it may be stable (i.e. neither eroding or prograding). The state that a beach is in largely depends on the supply of sediments to a shoreline. Sediment may come from rivers that supply surrounding beaches, the continental shelf and transported onshore by waves, or it may come from material eroded from surrounding shorelines and transported in the beach system.

A beach that is prograding has a ready supply of sediments and the wave and current activity by which to transport those sediments onto the shore. These beaches will generally respond quite well to sea level rise and may experience very little effects aside from an adjustment in the rate of progradation. However, this very much depends on the continual supply of sediments which may be altered if climatic changes modify local meteorological and hydrological conditions.

6.2.2 Eroding Shores

A shoreline in net long term retreat is likely to continue eroding under a rising sea level and quite possibly at a faster rate as wave run-up reaches higher up the beach. Long term erosion of a shoreline occurs when the amount of sediment being removed from the beach is greater than that being supplied by waves and currents. Shorelines currently eroding are extremely vulnerable to enhanced erosion under rising sea levels.

6.2.3 Stable Shores

Stable beaches are a fine balance between the sediment inputs and the wave conditions. These beaches can be seen to have a dynamic equilibrium with the local environment. Changes to this equilibrium may cause the beach to move into a period of long term erosion or progradation. However, under a rising sea level these shorelines will be more vulnerable to erosion, particularly if there is an increase in storminess.

All beaches experience short term episodes of erosion from storm events but are usually able to recover from this in ensuing months as sediment is transported back onshore. A prograding shoreline is able to recover from these erosion episodes quite quickly. However a stable beach may take much longer as the sediment supply is lower. A shoreline that has long term stability has developed a balance between these storm events and the ensuing calm periods. In other words it has developed a balance between the removal and supply of sediment to the beach. If an increase in storminess leads to a greater number of erosive episodes the balance may be disrupted and the beach becomes unable to recover in time before the next storm. In this way a beach that was stable may begin to erode as the removal of sediment becomes faster than the supply.

6.2.4 Gravel Beaches

The way in which a coast responds to sea level rise depends not only on the supply of sediments but on the type of material that the shoreline is composed. A hard rock shoreline may experience nothing more than more frequent inundation. Gravel and mixed sand and gravel shorelines, which make up about 25% of New Zealand's coast, respond differently than sandy coasts. On the whole gravel beaches are able to respond well to small changes in sea level and in many locations where there is a large volume of gravel, there may be no appreciable change in the beach.

Gravel beaches commonly have a stepped profile, composed of a series of berms. Berms provide a indication of the wave run-up on the beach and respond quickly to changes in wave conditions and water levels at the shoreline. Gravel beaches respond to changes in water level by adjusting the profile to contain the wave run-up. This results in the berm elevation being adjusted upward slightly and may result in the highest berm, known as the storm berm, moving slightly inland. Gravel barrier beaches that commonly occur at river mouths and in front of coastal lagoons are rolled back landward under a rising sea level. Gravel beaches do not have material removed from them or loose volume. Rather, the whole beach is translated inland. This may result in the loss of some productive land immediately behind the beach or barrier. By contrast, when a sandy beach retreats under a rising sea level, it occurs through erosion of sand from the foreshore and subsequent deposition offshore.

6.2.5 Estuaries and Inlets

Estuaries and inlets are particularly sensitive to changes in sea level because it alters the amount of water flowing in and out of them on every tide - a volume known as the tidal prism. Increases in the tidal prism can alter the inlet mouth and channels by causing an increase in the current velocities. This may lead to a widening of the entrance and scouring of the surrounding area. Adjacent beaches may experience severe erosion as they adjust to a new current flow regime. Sand deposition patterns may be altered leading to changes in the flood and ebb tide deltas and the position of sand shoals and channels in the inlet. It is possible that sedimentation rates will increase in many estuaries due to increased runoff from streams and hillslopes. This may offset some of the sea level rise, but lead to a loss or degradation of important coastal habitats for marine flora and fauna, including fish and shellfish species and bird life. To date, sedimentation rates in estuaries around New Zealand, that averages around 2-3 mm/yr, have been keeping apace with rises in sea level. However, this may change if sea level rise accelerates over the next 50-100 years.

6.2.6 Developed Coasts

On developed coastlines, especially low lying areas around estuaries, sea level rise may result in the loss of the inter-tidal zone and natural habitat. Many sections of coast around cities are commonly fixed in place by rock revetments, seawalls and road/rail causeways and are unable to naturally fluctuate. With rising sea level issues and increasing expensive assets at risk from erosion and inundation, there will be increasing pressure placed on local authorities to build more protection structures like these, thereby exacerbating the problem. There may be increased incidences of coastal flooding events as storm wave activity overtops walls and revetments. Enhanced scouring at the toe of these structures may undermine the wall and lead to its collapse. As the mean low and high water mark rises on a fixed coast the inter-tidal beach is unable to adjust naturally and the horizontal distance between the low and high water mark is squeezed, reducing the size of the inter-tidal area.

6.3 Climate Change Effects

Broader scale changes in the local climate may also alter the weather patterns of an area that has an impact on the incidence of storm wave events. For example, increased incidences of westerlies may lead to increased erosion activity along western parts of the New Zealand. Waves generated in the Tasman Sea tend to be steep, short period erosive waves that remove material from a beach. Increased storm events may lead to greater incidences of storm surge events and increased incidences of erosion and flooding.

7.0 Planning for Sea Level Rise

7.1 Statutory Regulatations

The effects of sea level rise are largely hazards related and can be managed through the planning and hazard management mechanisms contained within national and regional legislation. The over-arching piece of legislation is the Resource Management Act 1991. The Resource Management Act provides a mandate for Regional Councils to manage natural hazards:

- Section 30, 1(c) mandates Regional Councils to avoid or mitigate natural hazards.
- Section 31 states that Regional Councils must control any actual or potential effects of the use or development of the land including the avoidance or mitigation of natural hazards.
- Section 35 provides a mandate to conduct natural hazards research and maintain information on natural hazards.

A recent amendment to Section 7 states that particular regard shall be had to climate change effects.

Alongside the RMA, the Civil Defence and Emergency Management Act 2002 (CDEM) gives councils a mandate to identify, assess and manage hazards and to communicate information about the occurrence and effects of natural hazards. This can include the effects of sea level rise on coastal communities.

The RMA provided a mandate to produce the Zealand Coastal Policy Statement (NZCPS). This was completed in 1994. Section 3.4 of The New Zealand Coastal Policy Statement 1994 gives provisions for avoiding or mitigating the effects of coastal hazards. Policy 3.4.2 explicitly states that policy statements should recognise the possibility of a rise in sea level and should identify areas which would as a consequence be subject to erosion or inundation. As we have seen, there has been and continues to be a measurable rise in sea levels around the New Zealand coast. This Act is currently under review and it is expected that sea level rise and climate change issues will feature more prominently in the revised legislation.

Beneath the RMA and NZCPS sits the Regional Policy Statements (RPS). Regional Councils are required to produce Regional Policy Statements, that provide regulatory and non-regulatory polices to govern the management of natural resources at a regional level. Within this framework, Regional and Territorial Authorities are able to manage coastal hazards through statutory instruments such as regional, district and coastal plans under the Regional Policy Statement, the RMA and NZCPS.

Regional Council's are now close to the or in the process of reviewing their RPS's. Climate change and sea level rise should be an important issue for policy makers to consider in this process. Greater Wellington is currently reviewing its RPS and climate change issues including sea level rise are an important part of the hazard and coastal planning provisions. There are strong directional policies in the draft Wellington RPS for district plans to include provisions that avoid development in hazardous coastal areas. There are also a range of coastal hazard considerations for resource consents and notices of requirement.

7.2 Planning Responses

How a shoreline responds to climate change and sea level rise is a complex inter-relation between beach geomorphology, sediment supply and transport and the wave and current conditions. Shoreline response will also be affected by potential changes in the magnitude and frequency of storm events. Any management plans implemented to deal with sea level rise must be flexible enough to deal with coastal locations on a case by case basis, because different shore types react differently to changes in sea level. As a first step this may require some scientific research to provide a clearer picture of how a beach system may react, before implementing any planning and response programmes.

There are a number of responses that can be made to sea level rise:

1. *Modify the hazard.* In this case the aim is to reduce greenhouse gas emissions, with the main target being CO_2. However, there a long lag time between reducing CO_2 emissions and seeing a stabilisation of sea levels. In the mean time other measures will be required to deal with sea level rise impacts.

2. *Modify the losses*. This includes the damages resulting from sea level rise effects. This is primarily achieved through insurance mechanisms which can be through individual policies or collective/government schemes, such as EQC. This may be valid in the short term, or where the losses are low impact and infrequent, but it may not be a viable option in the long term.

3. *Modify the human element.* There are a range of options here that can be considered.

- Accommodation. This is a do nothing or very little response. This may be an option in areas with low level assets or where the impacts from sea level rise are expected to be low.
- Protection (e.g. seawalls, levees). This may be an option for very high level development, key infrastructure and high value property and assets, where the costs of loss or damage outweigh the cost of protection. In some areas this may be perfectly feasible. For example in main centres such as Auckland or Wellington where CDB's are adjacent sheltered harbours, the costs of protection will be found to outweigh the costs of no protection. Indeed, many of these areas already have a measure of protection. In some cases protection may be best

achieved through natural engineering methods such as, sand renourishment, dune planting and enhancing the natural buffering abilities of the coastal system.

- Adaptation. Some measure of adaptation will be required regardless of what happens over the next few years, because we are already locked into a certain amount of climate change and sea level rise. This may be a case a raising minimum floor levels to cope with increased coastal flooding, having setback distances from the coast, or by engineering deeper foundations to deal with possible erosion events. This may be an option where there is only occasional flooding and erosion. Another important aspect of adaptation is public education.

- Policy controls (e.g. avoidance, managed retreat). Avoidance can occur by preventing development in hazardous areas. This is possible with new development, through generous setback distances that allow the beach to adjust naturally to sea level rise without the need for engineering intervention. This may be an option in areas subject to repeated chronic flooding and ongoing retreat of the shoreline. Managed retreat will require bold and innovative policies by Regional and Territorial Authorities. Managed retreat may be an option for residential and industrial development that can be situated elsewhere, either further back on the section or further inland. Another option is buy back schemes, whereby Government or Local Authorities slowly purchase coastal properties and turn the land into reserve. Other methods for Local Authorities include non-renewal of resource consents, not allowing subdivision, new building or large scale renovations and only allowing owners to maintain their dwellings in a reasonable condition until the end of useful life of the building. In a worst case scenario it may require abandonment of the land, especially if it is eroding into the sea and the costs of protection outweigh the costs of the properties.

- Modify human behaviour. This can involved public education, by teaching people about the hazards of buying coastal property. This is one of the biggest challenges facing Local Authorities and government organisations, because coastal property is both both highly desirable and highly lucrative. Other methods include, placing hazard alerts on LIM and PIM reports or increasing insurance premiums. In extreme cases, it may be necessary to remove insurance cover altogether for high risk property locations.

Planning responses may involved a combination of these factors. For example, a solution may involve construction of a rock revetment to protect property in the short to medium term, with a longer term policy of retreat after the buildings and protection structures have reached the end of their usable life.

No single measure will solve all coastal planning issues related to sea level rise and climate change impacts. Planning for and dealing with the effects of sea level rise will involve a coordinated effort that involves a full spectrum of planning, education and engineering programmes from Central Government and Local authorities in cooperation with business's and communities.

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Using sea level rise projections for urban planning in Australia

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ABSTRACT

This study deals with incorporating predictions of sea level rise into practical municipal planning. Predictions of global mean sea level rise can be made with more confidence than many other aspects of climate change science. The world has warmed in the past century, and as a result global mean sea level has risen and is expected to continue to rise. Even so, there are significant uncertainties regarding predictions of sea level. These arise from two main sources: the future amount of greenhouse gases in the atmosphere, and the ability of models to predict the impact of increasing concentrations of greenhouse gases.

Current knowledge regarding the effect of global warming on sea level rise is reviewed. *Global mean* sea level is expected to rise by 3-30 cm by 2040, and 9-88 cm by 2100. An important remaining uncertainty is the future contribution of surface water storage (for example, lakes and reservoirs) to changes in sea level. In addition, there are also significant local sea level effects that need to be taken account in many regions of the globe, including isostatic and tectonic effects. The thermal expansion component of sea level rise is also likely to vary regionally, due to regional differences in the rate of downward mixing of heat and to changes in ocean currents.

The current state of planning for sea level rise in Australia is reviewed. While not all coastal municipalities include sea level rise in their planning schemes, the recent adoption in a number of States of new planning schemes with statutory authority creates a changed planning environment for local government. Coastal urban planning needs to take sea level rise into account because its effects will be apparent during the typical replacement time of urban infrastructure such as buildings (before about 70 years). For local planning, ideally a risk assessment methodology may be employed to estimate the risk caused by sea level rise. In many locations, planning thresholds would also have to be considered in the light of possible changes in storm surge climatology due to changes in storm frequency and intensity, and (in some locations) changes to return periods of riverine flooding. In the medium term (decades), urban beaches will need beach re-nourishment and associated holding structures such as sea walls. Changes in storm and wave climatology are crucial factors for determining future coastal erosion.

ADDITIONAL INDEX WORDS: Climate Change, Coastal Engineering

INTRODUCTION

Local governments face a number of issues when planning for future sea level rise. Sea level rise may accelerate the erosion of coastal margins, threatening land and property. It also diminishes the effectiveness of the buffer provided by the beach, bringing higher energy waves closer to the dune system. Rising seas may increase the incidence of coastal flooding, either by increasing the height of storm surges, or by acting as a higher seaward barrier restricting the escape of flood waters caused by excessive runoff. Since sea level rise is a confident prediction of climate change science, it has been the subject of numerous studies regarding its possible effects on coastal management issues.

The effect of the increase of "greenhouse" (heat-absorbing) gases has been assessed by the Intergovernmental Panel on Climate Change (IPCC; IPCC 1996, 2001). The IPCC found that the world is warming and that man-made technological processes are increasing the amount of greenhouse gases in the atmosphere. In its Second Assessment Report published in 1996, the IPCC stated that the balance of evidence suggested a "discernible human influence on global climate", while the Third Assessment Report (IPCC 2001) stated that "an increasing body of observations gives a collective picture of a warming world and other changes in the climate system." Nevertheless, it is important to emphasize that many of the projections of global change science are affected by uncertainties. These include not only the uncertainty caused by incomplete scientific knowledge, but also that inherent in the estimates of possible future greenhouse gas emissions. These "emissions scenarios" depend on assumptions about future global economic growth and technological change, so a wide range of such scenarios is usually given. New estimates for projected sea level rise are given in IPCC (2001).

The main reason that this is a relevant planning issue for local government is that the time frame of likely noticeable impacts of climate change (30+ years) lies within the typical replacement cycle of infrastructure such as large commercial developments and dwellings (about 70 years). Thus planners need to take climate change effects into consideration to minimize future impacts on new infrastructure and regularly need to monitor and review sea level projections to reassess their position. Here we focus on impacts and planning in Australia, in order to provide a comprehensive overview for this country that will be of use to researchers and coastal managers.

Section 2 reviews current sea level projections for the 21st century, while local planning implications of these results are discussed in Section 3. Section 4 provides some conclusions and recommendations.

THE SCIENCE OF SEA LEVEL RISE

Introduction

By its very nature, sea level rise is a long-term concern, as the effects of climate change are slow and will take decades to become apparent. We are therefore focussing on the amount of sea level rise that will occur by the year 2040, which is nevertheless within the typical local government planning horizon for building infrastructure. Projections for 2100 are also discussed.

Projected global mean sea level rise has several main components:

- thermal expansion of the oceans caused by warming;
- the melting of glaciers and small ice caps, also caused by warming;
- the contribution of the large ice caps (Greenland and Antarctica) to sea level changes through the melting and/or accumulation of snow; and

- changes in terrestrial storage.

In this study, the factors involved in estimating each of these components are described and the latest estimates reviewed. There are also factors that can cause regional variations in sea level, including the following:

- geological effects caused by the ongoing slow rebound of land that was covered by ice during the last Ice Age ("isostatic rebound");
- the flooding of continental shelves since the end of the last Ice Age, which pushes down on the shelves and causes the continent to push upwards in response ("hydro-isostatic effect");
- tectonic effects caused by changes in land height in volcanically active regions; and
- changes in atmospheric wind patterns and ocean currents that could be caused by climate change.

The effects of local subsidence caused by the compaction of sediments or by groundwater extraction can be very large. For planning purposes, this factor would have to be evaluated at site-specific locations (e.g. BIRD, 1993).

Global Mean Sea Level Rise

It is considered likely that the sea level rise in the 20th century has been largely caused by the observed increase in global surface temperature over the same period. Sea level has risen in the past century with increasing temperatures and climate models suggest that this warming will accelerate in the future; moreover, the thermal lag of the oceans caused by their very large heat capacity means that global mean sea level would continue to rise for the next several decades or longer even if there were no further production of greenhouse gases (WARRICK *et* *al.*, 1996; CHURCH *et al.*, 2001). This review largely summarizes the results of CHURCH *et al.* (2001), contained in IPCC (2001), the most authoritative recent report on climate change.

Global Sea Level Rise in the Past Century: Observations and Estimates

In the past century, global average sea level has risen by 10-20 cm, as measured by tide gauges located around the world (CHURCH *et al.*, 2001). To obtain a sea level change signal appropriate for the open ocean, tide gauge data must be accurately corrected for land movements and also must be long enough to separate out the year-to-year variability that occurs in many locations. Tide gauges represent the most accurate current record of sea level, however.

Additional measurements have been made from the TOPEX/POSEIDON spacecraft (NEREM *et al.*, 1997), which uses radar altimetry. This technique gives global average sea level at an accuracy of several mm every 10 days. The results still must be corrected for isostatic movements (PELTIER, 1998), but are not affected by tectonic movements or subsidence. Measurements are difficult, as high accuracy is needed. These data suggest that sea level is currently rising at about 1.5 - 3 mm yr^{-1} (CAZENAVE *et. al.*, 1999; NEREM, 1999). Since the satellite was only launched in 1992, the long-term accuracy of this technique is not yet well established, as a long record is required for robust trends to be estimated. The main confounding factor is the El Niño-Southern Oscillation (ENSO) effect, an oscillation in the sea surface temperatures (and other oceanic and atmospheric variables) of the Pacific Ocean that has an irregular period of about 2 - 7 years (see for example ALLAN *et al.*, 1996). It causes substantial variations in global average sea level every few years (NEREM *et al.*, 1999), and these affect the TOPEX/POSEIDON data recorded since 1992, as ENSO has been predominantly in a negative phase since this time. There is also some regional variation of sea level rise in the satellite data, which may reflect real variations from location to location (CHURCH *et al.*, 2001; LAMBECK, 2002).

The TOPEX/Poseidon data indicate a recent sea level rise that is faster than the mean rate estimated for the 20th century. CHURCH *et al.* (2001) were unable to ascribe the reason for the difference, attributing it either to a recent acceleration in sea level rise, systematic differences between satellite and tide-gauge measurements, or the shortness of the satellite record. GREGORY *et al.* (2001) point out that there is currently no discernible acceleration in the long tide gauge record. However, the detection of any significant acceleration is difficult with the present sparse geographical coverage of long gauge records.

Components of Observed Sea Level Rise

Thermal Expansion

Thermal expansion is the most important component of global sea level rise. In principle, the size of this component over the 20th century can be calculated from changes in oceanic temperature and salinity. Measurements are difficult, however, and complicated by the relative paucity of observations in the oceans. Nevertheless, comparison of regional and global observations suggests that thermal expansion has been proceeding at a rate of about 1 mm yr^{-1} over the past several decades (LEVITUS *et al.*, 2000; CHURCH *et al.*, 2001).

This is similar to the estimates of this quantity made by numerical models of the ocean over the same time period. These models range in complexity from simple upwelling/diffusion energy-balance climate models such as those of WIGLEY and RAPER (1987, 1993) and RAPER *et al.* (1996) to complex global ocean three-dimensional general circulation models (GCMs, also known as global climate models). A GCM solves equations that represent the fundamental aspects of the climate system, such as temperature, rainfall, winds and so on. Because of their complexity, GCMs are typically run on the largest and fastest supercomputers available. GREGORY *et al.* (2001) give a comparison of thermal expansion as simulated by a number of GCMs. These models display variability on decadal time scales that also occurs in the real ocean. This variability makes the analysis of trends more difficult, as decadal variations tend to obscure genuine long-term trends in the data, such as those associated with climate change.

Other simpler models include the two-dimensional model of DE WOLDE (1995, 1997) and the subduction model of CHURCH *et al.* (1991), subsequently developed by JACKETT *et al.* (2000). The major advantage of the simple models is that, because of their low cost, they can be easily modified and run for many different greenhouse-gas emission scenarios. Their main disadvantage is that they do not entirely realistically represent the processes involved in the penetration and distribution of heat into the ocean, and they have to be calibrated against GCM results. Additionally, they only give a global mean estimate and do not give any information on regional variations in sea level rise.

Based on observations and various model estimates, the contribution of thermal expansion to global sea level rise over the period 1910-1990 has been estimated at between 3-7 cm.

Glaciers and Ice Caps

It is clear that the vast majority of the world glaciers and small ice caps have been retreating in the past century, thereby contributing to global sea level rise. Nevertheless, it is difficult to calculate precisely their contribution. There are about 100,000 glaciers in various parts of the world with differing sizes, rates of melting and movement. Precise measurements of the "mass balance", or the net gain or loss of water by the glaciers, have only been made for a few of these. Instead, global estimates are made by dividing the glaciers into several main regions and estimating the mass balance for each region by assuming that the glaciers in each region all have the same mass balance as the specific known mass balance of a "typical" glacier in that region (KUHN *et al.*, 1999). There are also few observations of glaciers in regions that are considered important sources of meltwater, for example, the coasts of Alaska and Patagonia. Estimates that have been made (e.g. MEIER, 1984; MEIER, 1993; DYUGEROV and MEIER, 1997; GREGORY and OERLEMANS, 1998; COGLEY and ADAMS, 1998) suggest that glaciers and ice caps have contributed about 2 - 4 cm to global sea level rise over the period 1910-1990.

The Greenland and Antarctic Ice Sheets

The great ice sheets covering most of Greenland and Antarctica are governed by slower processes than those of smaller glaciers and ice caps. The complex dynamics of ice flow and interactions with the surrounding rock and sea make the process of estimating the contribution of these areas to global sea level rise a difficult task. Note that there are also extensive floating ice shelves, and in the past these have been affected by changes in temperature; for example, the break-up of the small Larsen Ice Shelf in Antarctica has been attributed to such temperature increases (ROTT *et al.*, 1995). Because these ice shelves are already floating, however, even if they melted completely, they would have no effect on sea level. It is the grounded ice (the ice resting on bedrock) on the continents of Antarctica and Greenland that has the potential to affect sea level. Together, these ice sheets contain enough water to raise the sea level by about 70 meters if they were to melt entirely (CHURCH *et al.*, 2001).

The large ice sheets gain mass by accumulation of snow, and lose it by melting, evaporation/sublimation, wind-driven snow drift and ice flow into the surrounding oceans. Since the response time for changes in ice flow is about 100 - 10,000 years (HUYBRECHTS and DE WOLDE, 1999), it is likely that the ice sheets are still adjusting to past melting and accumulation changes, particularly those associated with the end of the last Ice Age. In Antarctica, the low average surface temperatures imply that little surface melting occurs and ice loss is mainly by iceberg calving. In Greenland, by contrast, temperatures are higher, so melting and runoff are more important processes in the total mass balance (e.g. SMITH, 1999), and thus the response is quicker.

There is a contribution to the sea level rise that has occurred in the past century that is related to the slow adjustment of the ice sheets. This is because past changes in accumulation and melting rates take a long time to be reflected in changes in the rate of ice flow across the "grounding line", the line of contact between rock, sea and ice. The total mass balance of the grounded ice sheet is given by

$$\frac{dV}{dt} = Q_a - Q_m - Q_b - Q_g \qquad (1)$$

where Q_a is the annual net surface accumulation, the balance between snowfall, evaporation/sublimation and drifting snow; Q_m is the loss by surface melt; Q_b is the non-surface melting of the ice sheet; and Q_g is the movement of ice into the ocean, either through iceberg calving or flow across the grounding line.

The most accurate estimates of the long-term ice sheet contribution are made by combining model results (e.g. HUYBRECHTS and DE WOLDE, 1999) with evidence of sea level changes over the past several thousand years contained in the geological record. This comparison suggests an ongoing contribution of 0-5 cm from this effect during the 20th century.

The observed changes in temperature and precipitation in the 20th century would cause short-term changes in the mass balance of the ice sheets, which must be evaluated separately from the long-term contribution calculated above. Using the ice sheet model of HUYBRECHTS and DE WOLDE (1999), CHURCH *et al.* (2001) estimate that the contribution of Antarctica to global sea level over the past 100 years is between –2 and 0 cm, with the negative sign caused by increased accumulation of snow. The contribution of Greenland over the same time period is estimated as 0 to 1 cm.

Surface and Ground Water Storage

This term represents the changes in the quantity of liquid stored in the ground and in lakes and reservoirs, as well as the effect of changes in land use on runoff and evaporation. The contributions to sea level rise from these effects can be both positive and negative. Positive contributions could come from increased extraction of ground water and loss of wetlands, as these processes would increase the net water flow into the oceans. Negative contributions could come from surface reservoir and lake storage, and irrigation (GORNITZ *et al.*, 1997; SAHAGIAN, 2000).

Unfortunately, modeling of changes in hydrologic practices due to climate trends is in its infancy, and there are wide ranges of estimates of most of these terms. Current knowledge suggests that the net contribution from these effects to the total sea level rise could be important. GORNITZ *et al.* (1997) suggest an increasing storage of water on land and suggest the current rate could be as large as –1.2 to –0.5 mm yr^{-1}, with a central estimate of –0.8 mm yr^{-1}. On the other hand, VÖRÖSMARTY and SAHAGIAN (2000) give a much smaller value (and with the opposite sign), 0.06 mm yr^{-1} for the rate averaged over the 20^{th} century. This leads to a large range of the estimated contribution of this component to sea level in the 20th century. CHURCH *et al.* (2001) give a rate of –1.1 mm/yr to +0.4 mm/yr for the period 1910-1990.

Thawing of permafrost gives a positive contribution to sea level rise in the 20th century (ANISIMOV and NELSON, 1997) of 0-0.5 cm over the period 1910-1990 (CHURCH *et al.*, 2001).

Isostatic and Long-term Glacial Effects

In many parts of the world, land is still rebounding from the weight of the great ice sheets of the last Ice Age (for instance, Scandinavia; LAMBECK *et al.*, 1998). Comprehensive models of these effects have been developed (e.g. LAMBECK and JOHNSTON, 1998; PELTIER, 1998). In addition, many measurements of variables related to sea level have shown that sea level has varied with changes in ice volume during and since the last glacial period (SHACKLETON, 1987; YOKOYAMA *et al.*, 2000). Local isostatic effects can be very large, larger than the rate of global average sea level rise caused by global warming, and need to be assessed for the region under consideration.

Tectonic Land Movements and Local Effects

Changes in land height due to tectonic effects can be large in some locations: for example, the Huon Peninsula of Papua New Guinea, where uplift has averaged between 2 and 4 mm yr^{-1} (CHAPPELL *et al.*, 1996), and parts of the Mediterranean, were similar rates of uplift have occurred (STIROS *et al.*, 1994). These rates are large enough to reduce substantially or even negate completely the local impact of sea level rise.

In some locations, subsidence of land is important, for instance in river deltas (STANLEY, 1997). Man-made subsidence of land caused by groundwater extraction can be large in some locations (e.g. Bangkok; BIRD, 1993). These would have to be estimated very locally, as they may differ substantially even within the boundaries of a municipality. Other local changes in the relative level of sea and land are caused by the extraction of oil and gas reserves (BIRD, 2000).

Summary

The contributions of the various components to observed sea level rise during the 20th century are summarized in Table 1. The results in this table are for the observed global mean warming of 0.45°C ± 0.15 °C at the surface of the Earth over this time period. The estimates for the thermal component are based on simple models, while the glacier component is based on a combination of observations and models. Each component is associated with a range of uncertainty that is given by low and high bounds. The "total" amount of sea level rise referred to in Table 1 means the sum of all of the estimates of each component, while the "observed" amount is estimated from tide gauge records.

Obviously, a better determination of the components of the terrestrial storage term is needed. CHURCH *et al.* (2001) state that the quoted range for this term requires that several of its components lie simultaneously at the extremes of their ranges, which seems unlikely.

Future Global Sea Level Rise

The main tools used for estimating the future global and regional temperature changes needed to estimate sea level rise are climate models, usually GCMs. These models contain many interactions and approximations, some of which are not well understood. Nevertheless, they are the best available tools for the prediction of climate change, and their skill at representing the climate system continues to improve. A detailed description of the many current issues involved in climate modeling is contained in IPCC (2001). GCMs are used to estimate the response of the Earth's global mean surface temperature to changes in greenhouse gases, known as the *climate sensitivity*. Presently, there is a range of estimates of this quantity; this range represents a significant source of uncertainty in projections of future sea level change.

A range of projections of sea level in the 21^{st} century can be made, depending on assumptions regarding the future concentration of greenhouse gases and the actual sensitivity of the climate system to increases in these concentrations. Table 2 summarizes the predicted contributions from the various components of sea level rise for 2040 and 2100, as given by CHURCH *et al.* (2001).

The values for 2040 are calculated using the upper and lower limits of the GCM response for the climate-change related components of sea level rise. Note that these projections do not include a contribution from future changes in terrestrial storage. Future thermal expansion has been estimated using a number of GCMs (GREGORY *et al.*, 2001). These models differ both in terms of their climate sensitivity and the ability of their ocean components to absorb heat. Thus a range of 21st century projections of this component are calculated.

Sensitivity of the ice sheets to climate change has been estimated by multiple regression analysis, simple models and GCMs. For Greenland, the consensus is that higher temperatures would cause sea level to rise, given that surface melting of the ice there is likely to accelerate with global warming (WARRICK *et al.*, 1996; THOMPSON and POLLARD, 1997; SMITH, 1999; JANSSENS and HUYBRECHTS, 2000; WILD and OHMURA, 2000). For Antarctica, where significant melting is unlikely to occur because of the much lower temperatures typical of this continent, it is considered likely that increased temperatures may lead to increased snowfall over Antarctica over the next century, thus contributing to a sea level fall. For example, WILD and OHMURA (2000) suggest a value of -0.48 mm yr^{-1} $^{\circ}$C^{-1}.

An important point to note is that there is little sensitivity before about 2050 to different assumptions regarding the amount of greenhouse gases emitted into the atmosphere. In other words, for the range of greenhouse gas emission scenarios considered, the rate of sea level rise would be relatively unaffected until after about 2050. This is because the ocean is still warming up as a result of the greenhouse gases that have already been put into the atmosphere. Uncertainties in future emissions of greenhouse gases play a smaller part than model uncertainties over the next few decades, as the ocean has a substantial thermal inertia and responds only slowly to external forcing by greenhouse gases. For example, by 2050, CHURCH *et al.* (2001) suggest that the uncertainties due to emissions alone are only a few centimetres of total sea level. The effects of differing emission scenarios become larger towards 2100 and beyond.

Impact of Interannual and Decadal Variability on Sea Level

Interannual (year-to-year) variability of sea level is substantial in many parts of the world in the current climate. For example, in the South Pacific region, differences in mean sea level between El Niño and La Niña conditions are more than 30 cm in a number of Pacific locations (e.g. MERRIFIELD *et al.*, 1999; BELL *et al.*, 1999). It is likely that these variations will continue in the future (MEEHL and WASHINGTON, 1996; KNUTSON *et al.*, 1997; TIMMERMAN *et al.*, 1999). Nevertheless, projections of the effect of climate change on ENSO have considerable uncertainty. In constructing a scenario of future sea level change in regions where interannual variability is large, these variations must be taken into account. For future sea level conditions in these regions, the best current estimates might be made by simply assuming the same magnitude of interannual variation observed in the current climate and add these to the projections of global mean sea level rise given above.

Recent evidence has been found of decadal (longer than 10 years) variability in Pacific region sea level (BELL *et al.*, 1999; STURGES and HONG, 2001). This may need to be taken into account in the construction of the sea level rise scenarios in some regions. Decadal variability is an active area of research and its causes are not yet fully understood (e.g. CANE and EVANS, 2000).

Possible Collapse of the West Antarctic Ice Sheet (WAIS)

A more drastic sea level rise scenario involves the hypothesis that the western portion of the Antarctic ice cap is inherently unstable. This portion of the ice cap rests on bedrock that is below sea level over much of its area. Concern has been expressed that the west Antarctic ice sheet (WAIS) is vulnerable to changes in sea temperature, and there is a risk that it will discharge into the sea at greatly increased rates some time in the future. WARRICK *et al.* (1996) concluded that it was not possible even to estimate the likelihood of this occurring, as scientific results were not conclusive, with some authors suggesting that drastic rates of discharge were possible, while others suggested that they were not. BENTLEY (1997) argued that increased rates of discharge from the WAIS could only occur if a natural collapse was imminent, as the impact of climate change was unlikely to trigger it, for various reasons. Given the geological record, he estimated the probability of this occurring within the next century of about 0.1%. Even then, he considered that a "collapse" would only involve roughly a doubling of the expected rate of sea level rise rather than the rapid, massive slide of the ice sheet into the sea envisaged in some popular literature. CHURCH *et al.* (2001) conclude that based on our current understanding of the WAIS, a collapse was very unlikely in the 21st century. A panel of experts concluded that there is a 98% chance that a collapse will not occur this century, where a collapse is defined as a contribution from the WAIS to global sea level of at least 10 mm yr^{-1} (VAUGHAN and SPOUGE, 2002).

GCM Simulations of Regional Variations of Sea Level Rise

It is likely that there will be regional variation of sea level rise due to changes in ocean circulation as a result of global warming. Changed wind patterns will also change currents. These changes may be estimated using coupled ocean-atmosphere GCMs, but the results of various models currently differ considerably (e.g. GREGORY, 1993; CUBASCH *et al.*, 1994; BRYAN, 1996; JACKETT *et al.*, 2000; GREGORY and LOWE, 2000). GREGORY *et al.* (2001) show that projected sea level change is far from uniform spatially. Model results give some locations with sea level rise of more than twice the global average, while other regions show a sea level fall. Patterns simulated by the various models generally are not similar, but a few common features are seen. These include a minimum of sea level rise in the Southern Ocean south of 60°S and a maximum in the Arctic Ocean. In general, though, there is little consensus on the details of the regional distribution of sea level rise.

PLANNING FOR SEA LEVEL RISE

From Science to Planning

While the scientific evidence for future sea level rise seems convincing, the estimates of future sea level rise produced by (for example) WARRICK *et al.* (1996) or CHURCH *et al.* (2001) are not completely sufficient for planning purposes. The range of estimates is large, partly because of uncertainties in the current scientific knowledge of this issue, and partly because of different estimates of future greenhouse gas emissions. Planners would ideally like a projection of a particular sea level rise to be associated with a certain probability. It is not useful for planners if the entire range of predicted sea level rise is assumed to be equally probable. In any event, this cannot be the case, since the range is due to a combination of component ranges of uncertainty, and thus the extremes of this range must be less probable than the central estimate (JONES, 2001). Many of the GCM simulations reported in the current IPCC (2001) report have employed assumptions regarding the future emissions of greenhouse gases based upon the Special Report on Emissions Scenarios (SRES; NAKICENOVIC *et al.*, 1999). These various scenarios are constructed using very different postulated future world economic and social conditions to arrive at a selection of "storylines". When these storylines were constructed, it was explicitly stated that no probabilities could be attached to any of them; in other words, that no statement could be made regarding the likelihood of future world conditions actually resembling any of the storylines. One could not even assume that the story lines were equally probable.

For planners, this causes a difficult situation, as the projections of future climate made by GCMs using the SRES scenarios differ considerably between storylines by the end of the 21st century. The questioning of assigning probabilities to future global warming is now the subject of lively debate (e.g. PITTOCK *et al.*, 2001). Nevertheless, before 2050, this is not a significant issue, as the sea level rise projections before about this date are not strongly affected by differing emissions scenarios, a result of the large thermal inertia of the oceans and other components of the climate system. As mentioned earlier, the main source of uncertainty before 2050 is due to uncertainty about the science of sea level rise, not the future emissions of greenhouse gases.

What amount of sea level rise should therefore be assumed for planning purposes? The best approach might be through a risk assessment, based upon the estimated probability of various levels of sea level rise (e.g. JONES, 2001). Risk assessment aims to produce meaningful outcomes under conditions of high uncertainty. For sea level rise, risk assessment has taken two forms: as a probability distribution for a single outcome (e.g. the 95th or 99th percentile), or the calculation of the probability of exceedance above a given threshold identified as a hazard. TITUS and NARAYANAN (1996) concluded that a sea level rise of between 10 and 65 cm by 2100 had an 80% probability of occurring, while the 99th percentile was associated with a 104 cm rise. Alternatively, JONES (2001) suggests the use of critical thresholds, a concept that links an unacceptable level of harm with a key climatic or climate-related variable. For coastal impacts, the critical threshold is then linked to a projected range of sea level scenarios, through key climatic and marine variables, and the risk of exceedance of the threshold is calculated. JONES (2001) gives an example based on the joint probabilities of exceedance of a sea level threshold and the influence of atmospheric CO_2 on coral reef carbonate growth. For all types of risk assessment, the scenario-building exercise should incorporate all ranges of uncertainty that can be quantified, whether by expert analysis, dynamic modeling or statistical methods (usually a combination is applied).

One method would involve combining a probability distribution of sea level rise with detailed information on the vulnerability of infrastructure such as buildings (ABBS *et al.*, 2000), leading to a cost-benefit analysis of the cost of regulation versus the benefits of reducing damage. This is a complicated procedure, requiring as it does excellent land elevation data and good knowledge of the value of infrastructure under threat. Local probabilities for sea level rise were estimated for the United States by TITUS and NARAYANAN (1995). They provided a methodology for combining projections of future global sea level with local changes in sea level due to land subsidence and other factors detailed above.

While this approach is desirable, simpler interim solutions have been adopted. For example, BETTS (1999) devised a planning scheme for sea level rise in the City of the Gold Coast in Australia. This was based upon projections of sea level rise by 2050 for the Gold Coast made by WALSH *et al.* (1998), which were estimated from the following components: the predicted global mean sea level rise contained in WARRICK *et al.* (1996), of 10-40 cm; the hydro-isostatic effect in the Gold Coast region, -2 cm; and an uncertainty factor which allows for possible geographic variations in sea level rise, -5 to + 20 cm, reflecting possible regional deviation from the global mean sea level rise. This gives a total of 3-58 cm, with a central estimate of 18 cm. This range remains consistent with the later sea level estimates of CHURCH *et al.* (2001) detailed in Section 2. Tectonic effects and interannual variations caused by ENSO are small in the Gold Coast region. Possible large effects caused by land subsidence were not explicitly considered in the planning guidelines, as these would have to be estimated very locally. The regional variation estimate could be improved by using spatial patterns of sea level rise similar to those recently produced by GREGORY *et al.* (2001).

BETTS (1999) assumed that the central estimate of sea level rise thus calculated (18 cm by 2050) was not conservative enough for use in planning, as almost by definition the central estimate would have a 50% chance of being an underestimate. Thus a slightly higher sea level rise allowance was made. BETTS (1999) assumed a sea level rise of 30 cm by 2050 (subsequently modified to 27 cm, this being the central estimate for 2070 estimated by WALSH *et al.*, 1998; BETTS, 2001). This planned allowance for sea level rise is on top of an existing 30 cm freeboard allowance above the 1 in 100 year flood level, the planning approach used in the current climate. Ideally, however, a risk assessment based upon a probability distribution of sea level rise would be a preferred method. Note, though, that sea level will continue to rise well past 2100 for all but the most stringent emissions scenarios (see CHURCH *et al.*, 2001 for details).

An increase of sea level would restrict the outflow of flood waters from local river systems into the ocean, thereby increasing peak flood levels. Damage estimates in the region are very sensitive to increases in flood levels. The estimated flood damage in a portion of the Gold Coast region has a very non-linear increase in damage with flood height. Higher sea levels and storm-generated wave set-up could also cause changes or even breaches in low dune systems, although riverine runoff poses the greatest flood risk in this region (MCINNES *et al.*, 2002a) and the incidence of such flooding may not be strongly influenced by sea level rise. In some locations, the interaction between river flooding and sea level rise has the potential to raise flood levels substantially in a number of locations (e.g. ARNELL, 1999; NICHOLLS *et al.*, 1995).

As mentioned earlier, the life of assets such as dwellings is long enough potentially to be affected by climate change. For the purpose of the Gold Coast planning scheme, an average life of assets of 50 years was adopted, but building platform levels were required to remain above peak flood levels 70 years hence. Other long-lived infrastructure, such as main roads, bridges, ports and harbours, may also be affected on these time scales.

Impact of Sea Level Rise on Storm Surges

Although not explicitly considered in this paper, the climatology of storm surge events will be affected by sea level rise in vulnerable locations. To incorporate sea level rise into estimates of storm surge return periods, it is usually adequate simply to add the sea level rise linearly to the storm surge height (e.g. ABBS *et al.*, 2000; MCINNES *et al.*, 2002b). The effects of climate change may also included regional changes in storm frequency and intensity, which may affect the storm surge return periods in particular locations (IPCC, 2001). The vulnerability to storm surge needs to be estimated at specific locations, as it depends on the details of geography and ocean depth at a particular location. For example, MCINNES *et al.* (2002b) found that the increase in the 100-year storm surge height due to storm intensity changes is greater than the contribution due to sea level rise at a location on the northeastern Australian coast. In particular, increases in intensities of tropical cyclones are now considered "likely, in some locations" (IPCC, 2001), which would have effects on the storm surge climatology in some Australian locations. Increases in mean sea level will exacerbate flooding in regions already vulnerable to storm surge.

Impacts and Practical Planning

There is a substantial literature on practical planning for sea level rise (e.g. BILJLSMA *et al.*, 1996; IPCC CZMS, 1990; KLEIN *et al.*, 1999; TITUS, 1998; NICHOLLS *et al.*, 1999; NICHOLLS and MIMURA, 1998). Sea level rise itself does not cause coastline recession; it is the resulting changes in the wave climate and alongshore transport that causes increased erosion (e.g. LEATHERMAN, 2001). For beaches, the rate of lateral beach erosion is typically two orders of magnitude greater than the increase in sea level (LEATHERMAN, 2001). This relationship was first enunciated by BRUUN (1962) and is known as Bruun's rule. Although this model is highly simplified compared with real beach processes, it forms the basis of a number of planning strategies for sea level rise in Australia and elsewhere.

Responses to sea level rise can be classified into a series of human adjustments that can be used to identify potential effects on beach and dune resources (NORDSTROM, 2000). TITUS (1990) gives the following classification system for management strategies:

- accommodation/no protection;
- protection (e.g. levee or sea wall);
- adaptation (e.g. island raising);
- retreat.

For urban areas, accommodation or abandonment is generally not a viable option, as the cost of the infrastructure to be abandoned is often too high. An exception is low-lying urban regions containing little infrastructure e.g. wetlands.

Protection has the advantage is that it does not require major institutional changes regarding land use. For example, a beach could still be maintained by artificial nourishment, the placing on the beach of sand obtained elsewhere. This strategy is costly and depends upon a ready supply of sand, which may not be available for all locations. On the east coast of the USA, the cost is around US$10,000 per beachfront lot per year (PILKEY and HUME, 2001). Because of the cost of this process and the limited supply of sand for nourishment, urban planners could be faced with some hard choices regarding the future of urban beaches in regions where the mean sea level is rising.

Alternatively, sea wall construction costs are estimated at about US$3000 (1998 dollars) per linear metre, with maintenance costs of 4-10% per annum, depending on exposure to wave action (NEUMANN and LIVESAY, 2001). For aesthetic and amenity reasons, in vulnerable urban areas, a combination of sea wall construction and beach nourishment may be necessary (see Figure 1). Timelines for the construction of protection works need to be carefully considered. YOHE *et al.* (1999) pointed out that postponing protection works until the decade when they are needed could save costs of an order of magnitude. Strategies to deal with sea level rise must be local because of the very heterogeneous nature of the coastline (NEUMANN and LIVESAY, 2001). Sea walls in tourism areas may well protect beach-front infrastructure but reduce the attractiveness and viability of the area as a resort.

Island raising involves putting sand on the beach, as well as raising the nearby buildings and support infrastructure. Advantages of this strategy include that no one is prohibited from building or rebuilding, and the government does not have to buy property (TITUS, 1990). Disadvantages include the cost and environmental problems in dredged areas from which the sand and fill material would have to be extracted.

Engineered retreat mimics natural retreat by artificially filling the bay sides of barrier islands while the ocean side erodes, a strategy recommended for barrier islands off the coast of the United States. A regulatory strategy that could encourage an efficient private response to sea level rise involves a system of rolling easements, whereby development is prohibited progressively further inland as time goes on (TITUS, 1998).

Alternative descriptions of these management strategies have been proposed. KAY *et al.* (1996) prefers the nomenclature used in natural hazard research:

- event protection
    - hard: sea walls
    - soft: beach nourishment
- damage prevention
    - avoidance – prevent development
    - mitigation – building codes, flood-proofing
- loss distribution
    - individual – insurance
    - community – insurance/relief/cost sharing

- risk acceptance
    - includes doing nothing

As already mentioned, sea level rise *per se* does not cause geomorphic change: extreme wave activity does. Thus it is possible that in some locations beaches may not recede despite relative sea level rise. In this context, BELL *et al.* (2001) examined the impact of climate change on the coastal margins of New Zealand. The prediction of shoreline response to climate change is complex, and beach response will depend upon factors such as sediment supply, wave climate, storm frequency and alongshore changes in sediment movement, not just on the amount of relative sea level rise. Wind and wave changes in particular could have a substantial effect, and much less work has been done to examine changes in these factors in a warmer world. Projected increases in storm rainfall intensities (e.g. CSIRO, 2001) could lead to increased sediment flow in some locations. For example, the Pegasus Bay shoreline response study (BELL *et al.*, 2001) showed that plausible changes in wave climate or sand supply could *reverse* the beach recession caused by sea level rise.

In summary, for developed urban areas in the long term, managed retreat may need to be considered, as other strategies will become increasingly expensive. In the medium term (decades), urban beaches will need beach re-nourishment and associated holding structures such as sea walls. Changes in storm and wave climatology are crucial factors for determining future coastal erosion.

Current Regulatory Environment in Australia and New Zealand Regarding Sea Level Rise

In planning for sea level rise, the scientific issues need to be put into the context of management decisions and the present regulatory regime that governs response options. For Australia, this topic was previously reviewed by KAY *et al.* (1996). Both New Zealand and

Australian regulations are examined here, as until recently one of the major differences between the two countries was that New Zealand had a statutory regional planning process, whereas in Australia plans were mostly non-statutory i.e. did not have the force of law.

New Zealand

BELL *et al.* (2001) give a summary of the current regulatory environment in New Zealand. They surveyed local authorities to assess the degree to which current statutory plans have taken sea level rise into account. Quite a few local councils have specifically included sea level rise in plans. Mostly they use IPCC projections without regionally-varying relative sea level rise caused by other factors. A need was identified for improved and more accurate topography and coastline data to categorise local vulnerability better.

Australia

National: National guidelines on responding to the effects of climate change in coastal engineering design were published by the INSTITUTION OF ENGINEERS, AUSTRALIA (1991). More recently, INSTITUTION OF ENGINEERS (2000) identified marine climate change and its effect on the coastal zone as the most important research priority for coastal and ocean engineering in Australia.

As part of the National Local Government Coastal Management Policy of the Australian Local Government Association, the Intergovernmental Coastal Reference group has been established by State and Local governments across Australia to discuss matters relating to coastal policy as well as management. The National Oceans Office is a Commonwealth Executive Agency whose role is to coordinate the development of regional marine plans and the overall implementation and development of Australia's ocean policy. In the context of sea level rise, Australia's Oceans Policy recommends improved monitoring of sea level.

Victoria: In Victoria, overall strategic direction for planning and management of coastal areas is provided through the Victorian Coastal Strategy that is developed and endorsed by the State Government pursuant to the Coastal Management Act 1995. Both the 1997 Strategy and the recently released Victorian Coastal Strategy 2002 identify a requirement for coastal planning and management bodies to take a long-term approach to planning and decision making having regard to risk issues including changed climatic conditions and storm events. The Act requires that managers of coastal areas give effect to the Strategy.

The Strategy encourages a program of vulnerability assessment within a 100-year planning horizon as a basis for detailed statutory planning. The Victorian Coastal Strategy is specifically referenced in the State Planning Policy Framework and is required to be taken into account by planning authorities through planning schemes. A range of studies and modeling assessments are underway, as part of the Federal Government's Greenhouse Strategy and Coastal Strategy commitments, to develop improved estimates for detailed planning.

Regionally, several initiatives have been taken to encourage greater understanding and to improve planning predictions. A study is currently under way, focusing on the Gippsland Lakes region, to establish a consistent methodology for the calculation of the 1% flood probability in estuaries (TAN *et al.*, 2001). Once this methodology is established, it is anticipated that it will be widely applied elsewhere. If successful, this will enable a better delineation of estuarine vulnerability to sea level rise.

At the local level, guidelines for allowances for flooding are set by local municipalities and Catchment Management Authorities. A typical freeboard allowance in floor level heights would be 300 mm above the 1 in 100-year average recurrence interval of river or sea level, but this has not specifically included sea level rise. In terms of specific management initiatives at the local level, these have been limited. In Victoria, possible vulnerable urban areas include sections of the Port Phillip Bay coastline from Port Melbourne and Brighton and other parts of both the eastern and western shores, as well as towns in the Gippsland Lakes region such as Lakes Entrance (COASTAL INVESTIGATIONS UNIT, 1992; MCINNES and HUBBERT, 1996).

Tasmania: Tasmania's coastal policy is a statutory document and contains some recommendations about the need to take sea level rise into account in planning. These recommendations are quite general, however, and to date no real planning decisions have been made on the basis of them.

The Tasmanian State Coastal Policy (http://www.delm.tas.gov.au/env/coastpol.html) states that "policies will be developed to respond to the potential effects of climate change (including sea level rise) on use and development in the coastal zone." Other than the general direction set by the State Coastal Policy, the State Government does not currently offer guidance to planning authorities on considering climate change in the planning process. Approximately ten years ago, the Commissioner for Town and Country Planning advised Councils that they should consider the climate change implications to proposed coastal subdivisions. As a result, some councils did include this issue in their planning schemes and others considered it as part of the subdivision approval process. The replacement of the Commissioner by a Panel and now by the Resource Planning and Development Commission has seen this requirement decline in perceived importance. No specific planning advice or requirement has been provided to Councils by the Commission or State Government in recent years.

Tasmania has six Regional Coastal strategies; these are non-statutory documents and cannot directly affect the planning process. Twenty-three out of twenty-four coastal Councils are involved in these Strategies and where appropriate will amend planning schemes to reflect priority recommendations.

In 1995, Tasmania carried out a case study on South Arm in the Clarence municipality as part of the National Coastal Vulnerability Assessment Case Studies Project funded by the Federal Government. More recently, the whole coast of Tasmania has been assessed to identify and locate the type and extent of geomorphic types around Tasmania. Further work is being carried out to identify how this information can be used to analyse coastal vulnerability to climate change effects over the next century. A pilot project for part of the coast will occur this year (2002), but its extension around the entire coast will need to await further funding.

New South Wales: The NSW Government is currently undertaking a three-year comprehensive coastal assessment with the objective of identifying (for planning) those areas of the coast that may reasonably be developed. Areas of significant ecological, social or heritage values and those areas likely to experience significant future coastal hazard will be quarantined. In New South Wales, coastal management plans are prepared through local coastal management committees constituted by local government. These plans are jointly funded by State and local government and undergo a defined management process outlined in the NSW Coastline Management Manual. Definition of the coastal hazards takes into account the impact of sea level rise and future shoreline recession. This manual is currently being rewritten and will amalgamate both coastal and estuarine planning procedures for NSW. It will promote a risk-based approach to addressing coastal and estuarine hazards.

Changes to the NSW coastal legislation currently before the parliament will, amongst other things, require coastline management plans to be formally gazetted. In approving these plans the state government may ensure that sea level rise is appropriately considered.

The existing manual for preparation of coastal management plans in NSW (since 1990) has included guidelines requiring consideration of sea level rise in defining coastal hazard areas.

Over recent years, consultants preparing studies for Councils have simply applied the Bruun rule to IPCC mid-range scenario projections. Generally, this has resulted in a recommended allowance of an additional setback of 10 m to 20 m over a 50-year planning horizon. Virtually all local coastal councils in the State have included such an allowance in the hazard definition studies upon which their management plans are subsequently based. For example, the city of Newcastle is currently developing a city-wide coastal management plan that includes broad consideration of sea level rise issues.

Queensland: The recently promulgated State Coastal Management Plan was scheduled for implementation in February 2002[1]. The State coastal plan describes how the coastal zone is to be managed as required by the Coastal Protection and Management Act 1995, and is a statutory document. The State plan states that coastal management plans must address the potential impacts of climate change through management approaches along the lines of those mentioned in section 3.2. Regional coastal plans are to operate in combination with the State Coastal Plan.

The Plan states: "Planning for the coast must address the potential impacts of climate change through the following hierarchy of approaches:

- avoid — focus on locating new development in areas not vulnerable to the impacts of climate change;
- planned retreat — focus on systematic abandonment of land, ecosystems and structures in vulnerable areas;
- accommodate — focus on continued occupation of near-coastal areas but with adjustments such as altered building design; and
- protect — focus on the defence of vulnerable areas, population centres, economic activities and coastal resources."

It further states: "Where areas vulnerable to stormtide inundation have been developed, further development in these areas needs to address vulnerability to sea level rise and storm tide inundation".

Since the State plan has only recently been promulgated with statutory authority, to date the local planning in Queensland for sea level rise has varied considerably. Recent local planning for sea level rise includes that of the Gold Coast City Council, discussed in section 3.1.

South Australia: There is a long history of allowance for sea level rise in local planning in South Australia (SOUTH AUSTRALIAN COAST PROTECTION BOARD, 1992). Current provisions for sea level rise in development plans around the state allow for sea level rise of 300 mm over 50 years, plus the capability of being protected against further sea level rise of 0.7 meters, using protective measures such as sea walls and setbacks. All local council development plans incorporate sea level rise in their planning schemes.

Western Australia: The recently released draft State Coastal Statement of Planning Policy (coastal SPP) is a policy that must be taken into account by decision makers in coastal planning. The coastal SPP will guide development of coastal regional strategies, local planning strategies, and regional and town planning schemes. The SPP includes a schedule on the calculation of setbacks to ensure that development is setback from coastal processes as well as taking into consideration natural attributes such as wetlands and conservation of biodiversity, and recreational needs. The calculation of coastal processes is a three-part process, including calculation of three components: the trend of erosion or accretion; the incidence of extreme storm events; and the magnitude of sea level rise. The sea level rise component has been derived from IPCC (2001) and is taken to be 38 cm, translating into 38 m by the Bruun rule. The three

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[1] (http.//www.env.qld.gov.au/cgi-bin/w3-msql/environment/coast/management/msqlwelcome.html?page=sp.html

calculated components are added to provide the setback for coastal processes and then the site-specific attributes and recreational needs are also considered to determine the total setback for development from the coast. It is likely that the setbacks may become incorporated into statutory planning through regional and town planning schemes in coastal areas where development pressures are most keen. Note that most of the WA coastal foreshores (more than 97%) are in some form of government ownership and hence the need to protect private coastal development is very limited in this State.

Summary

In summary, not all local councils in Australia have included sea level rise in their planning schemes. The recent adoption of statutory planning schemes in a number of States indicates a change in the local planning environment, however.

4. DISCUSSION AND CONCLUSION

In this paper, the latest estimates of both global mean and regional sea level changes in the 20th and 21st centuries are reviewed. In many locations, regional and local effects of sea level rise or fall need to be incorporated to make site-specific projections. Ideally, a risk management approach that combines the projected probability of sea level rise (the hazard) with the damage to the infrastructure affected (the vulnerability) could be used. JONES *et al.* (2002) offer a modified definition of these terms, where hazard is the critical threshold of damage, risk is the likelihood of the threshold being exceeded and vulnerability increases as the risk of damage increases. In the meantime, a number of simpler planning recommendations have been made. In general, the use of the central estimate (or most likely value) of sea level rise is insufficiently conservative for planning purposes, and higher values should be assumed. The impact of sea level rise on the ability of flood waters to escape into the open ocean and on storm surge return periods needs to be assessed for each location.

There has been a considerable amount of research focused on the issue of sea level rise itself. There has been rather less work on the possible changes in wind and wave climate in a warmer world, despite the fact that studies have shown that these, combined with changes in sediment transport, can accelerate or even reverse the shoreline recession caused by sea level rise. Climate change research priorities for coastal environment therefore should include changes in the wind and wave climate of the coastal environment, and changes in rainfall, which affects runoff and sediment deposition (INSTITUTION OF ENGINEERS, 2000). This is particularly important in locations currently vulnerable to storm surge.

The wide range of estimates of future sea level rise is still a problem for planning. The real issue for coastal planners should be the changes in the frequency of extreme sea level events and changes in wave climate; relatively small increases in mean sea level can cause substantial increases in extreme events. In addition, there appears to be substantial long-term variability in shoreline erosion, with erosion events perhaps related to decadal variations in the climate system such as the Pacific Decadal Oscillation (MANTUA *et al.*, 1997; BELL *et al.*, 1999).

It is clear that for highly developed urban coastal areas, protection options such as sea walls and beach nourishment will be employed to combat sea level rise for some time to come. Nevertheless, as the sea continues to rise, towards the end of this century these options will become increasingly expensive. It may be that some difficult choices will have to be made regarding whether protection continues for particular locations, or whether retreat and adaptation is employed instead (e.g. BELL *et al.*, 2001; LEATHERMAN, 2001).

The recent adoption of statutory coastal planning schemes in some States in Australia will probably lead to a change in local government planning responses to sea level rise, as not all local government authorities currently include sea level rise in their planning schemes. While this paper gives a broad overview of current planning for sea level rise in Australia, perhaps a survey is needed of current local government planning responses along the lines of that previously performed for New Zealand (BELL *et al.*, 2001). In addition, there is currently no Australian national program to fund coastal climate change impacts projects. This is limiting the response by local municipalities to sea level rise and other coastal climate change impacts.

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Table 1. Estimated contributions to sea level rise over the twentieth century (in cm). After CHURCH *et al.*, (2001).

Component	Low	Middle	High
Thermal expansion	3	5	7
Glaciers/small ice caps	2	3	4
Surface water and ground water (terrestrial) storage (not climate change)	-11	-3.5	4
Greenland ice sheet (20th century)	0	0.5	1
Antarctic ice sheet (20th century)	-2	-1	0
Ice sheets – adjustment since last Ice Age	0	2.5	5
Other	0	0.3	0.5
TOTAL	-8	7	22
OBSERVED	10	15	20

Table 2: Total predicted global mean sea level rise for 2040 and 2100 (in cm).

	Low	Mid	High
2040	3	12	30
2100	9	48	88

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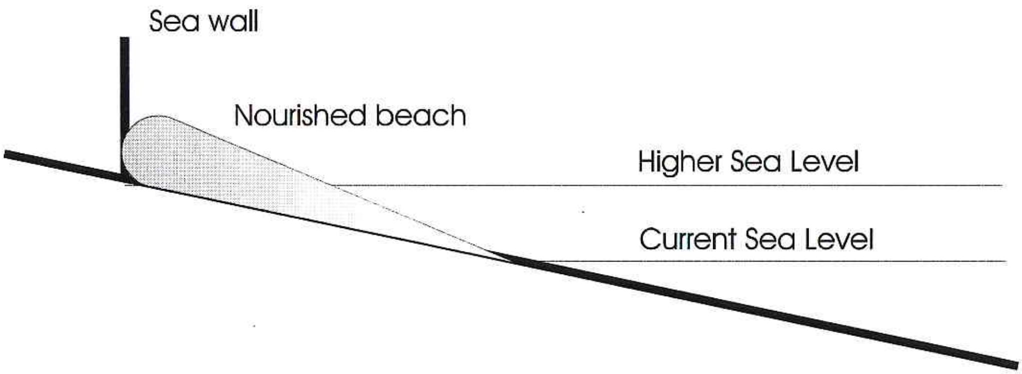

Figure 1. Schematic diagram of response to higher sea level, including a sea wall and a nourished beach.

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Friday, 12 December 2008 | 10:03 PM

Mandurah 'could be under water by 2070'

23rd October 2008, 6:45 WST Rising sea levels could see parts of Mandurah foreshore under water by 2070, according to climate change predictions that have sparked a $100,000 coastal risk study.

Mandurah City Council has become the latest municipality to employ consultants Coastal Zone Management to outline future scenarios and formulate an action plan for its coastal zone and waterways.

A similar study for Cottesloe in June found its beachfront and many of its multi-million-dollar homes would be destroyed by a projected sea level rise along the WA coast by 2070.

CZM principal consultant Robert Kay said yesterday that Mandurah had a lot of low-lying land, which could be prone to erosion and inundation from rising sea levels. However, he believed measures could be taken to stem any impacts.

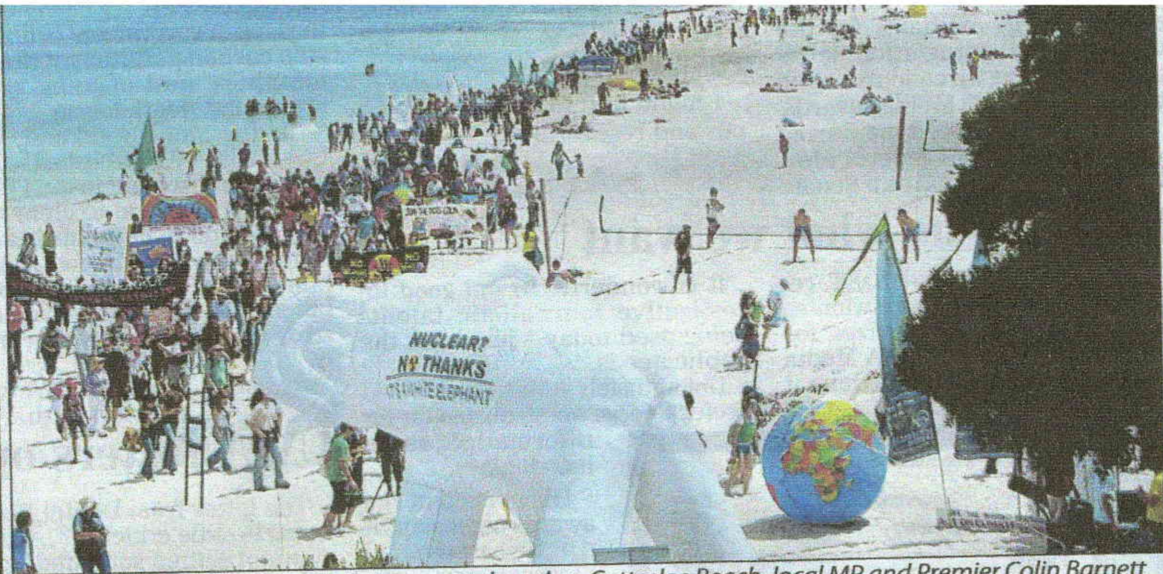
Mandurah mayor Paddi Creevey said the council needed "local science" to identify what areas were vulnerable. "We feel we just can't wait, we have to find out what it is we need to do," she said.

The report for the Town of Cottesloe also warned that violent storms meant infrastructure could be destroyed and homes left without vital services such as gas, water and sewerage if the State Government failed to assess Marine Parade pipelines.

In June, Federal Climate Change Minister Penny Wong said an estimated 28,000 buildings and 641km of road between Fremantle and Mandurah were at risk because of rising sea levels.

BEATRICE THOMAS

Have your say



As global warming activists protesters gathered on Cottesloe Beach, local MP and Premier Colin Barnett was preparing to lift the ban on uranium mining.

CLARE MONT + NEDLANDS POST 22/11/08

Save our planet!

More than 1000 people rallied at Cottesloe Beach last Sunday along with thousands more across the nation in Australia's biggest call for climate change action.

Cottesloe Beach was a colourful sea of people of all ages demanding governments take much more urgent and serious action to stop global warming.

Cottesloe mayor Kevin Morgan told the crowd that the Indiana Teahouse could be under water by 2030 if serious action on climate change was not taken today.

"Doing nothing is not an option," he said.

Speakers, including Environment Minister Donna Faragher, Opposition Leader Eric Ripper and WA Greens senator Scott Ludlam, addressed the rally.

Premier Colin Barnett, Liberal MP for Cottesloe, was in Kalgoorlie.

Three days later, he announced the end of the ban on uranium mining in WA.

Organiser Carolyn Hofmeester said: "Today's message was clear. The community demands serious action, strong emission reduction targets, greater investment in clean energy – and not nuclear.

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• From page 1

"If we fail to take immediate action, then as well as losing Cottesloe we risk losing many of our other beautiful beaches from Yallingup to Cable Beach and natural icons including our amazing Ningaloo Reef and our magnificent forests in the South-West.