

## Impacts of Climate Change in New Zealand and the Required Response: An Engineering Focus on Coastal Margins, Human Settlements, Infrastructure and Water Resources by J.D.N. Gluckman and C. A. Boyle

### 1. ABSTRACT

Engineers have a significant role to play in responding to the impacts of climate change in New Zealand. While continuing to provide innovative and cost-effective solutions, engineers must take a proactive approach towards planning and managing the expected impacts of climate change. In particular, engineers are likely to be involved in the completion of regional climate-change hazard assessments, an important next step in planning for a warmer future. If the impacts of climate change are to be managed effectively, an integrated and precautionary approach is required. In the coastal environment, engineers must implement a range of complementary planned retreat, adaptation and protection measures. In the built environment, engineering responses must be supported by strategic and precautionary policy, particularly regarding flood risk management. With regard to water resources, integrated catchment management is likely to be the most effective means of managing the impacts of climate change. In addition to implementing diverse physical and managerial measures, engineers also have an important role to play in driving the integration of these measures, which is essential if we are to overcome the challenges posed by climate change and move towards a more sustainable future.

### 2. INTRODUCTION

Engineers are the designers and managers of much of the technology and infrastructure upon which our society is based. As such, in addition to providing constructive solutions to problems, they should be encouraging proactive precautionary measures to safeguard the environment and help move towards a more sustainable future. This dual role as problem-solver and framer is particularly important regarding climate change, as engineers must work

both to develop more environmentally benign technologies in order to reduce and avoid greenhouse gas emissions and also to plan and design for a warmer future [not a contestable point – doesn't require backing and gains nothing from the citation]

The purpose of this research was to investigate the role of engineers in planning for and adapting to the impacts of climate change in New Zealand. A particular focus was given to coastal margins, human settlements, infrastructure and water resources, as areas in which engineers, particularly civil and environmental engineers, are likely to play significant roles. This research sought to identify and recommend tangible actions to be undertaken by engineers to mitigate adverse effects and maximise benefits associated with climate change in New Zealand.

It is important to note that this research was focused on the role that engineers must play in responding to the impacts of climate change. Although it must be recognised that engineers also have a major role to play in reducing anthropogenic contributions to climate change, particularly greenhouse gas emissions, this was considered beyond the scope of this research. The mechanism of climate change is such that, even if steps were taken now to prevent further emissions of greenhouse gases, the climate would continue to change as a result of past activity. This is primarily because oceans act as heat reservoirs (Houghton *et al.*, 2001). This 'lag' in atmospheric response means that some climate change is already inevitable and the requirement that engineers accept, accommodate and plan for this inevitable change was the focus of this research.

### The Science of Climate Change

The science of climate change has been controversial. Fenwick *et al.* (1998) provide a balanced overview of the arguments surrounding the phenomenon of climate change. The purpose of this research was to not investigate the veracity of the claims of supporters and opponents of various climate change theories. Rather, this controversy is acknowledged, while accepting the growing consensus that climate change is indeed happening and that continued anthropogenic emissions of greenhouse gases will only exacerbate this rate of change (Houghton *et al.*, 2001).

The Intergovernmental Panel on Climate Change (IPCC), the major international authority on climate change, has concluded not only that the world is indeed getting warmer, but that there is “new and stronger evidence” that most of the warming observed over the last 50 years may be attributed to human activities. On average, global temperatures are currently 0.6°C higher than they were during the late 19<sup>th</sup> century, and it is likely that the 1990s were the warmest decade of the last millennium. Over the period to 2100, the globally averaged surface temperature is projected to increase by 1.4– 5.8°C relative to 1990 levels, accompanied by a rise in mean sea-level of between 9 and 88cm, largely as a result of thermal expansion and ice-melt. Increased precipitation intensities are also very likely (90– 99% confidence) (McCarthy *et al.*, 2001). Houghton *et al.* (2001) provide a detailed scientific basis for these projections.[There is no need to cite them after each point, given this general citation]

The range of values observed in these climate projections is generated by using different global climate model (GCM) ‘scenarios’ pertaining to future unknowns such as greenhouse gas emissions, technology levels, economy and population. This wide range is also representative of the fact that different parts of the planet will experience different changes in climate (McCarthy *et al.*, 2001). The high levels of uncertainty associated with climate projections require that a precautionary approach be taken towards any future development. This need to operate in a precautionary paradigm is a feature of future planning that must be acknowledged and adopted by the modern engineer.

### 3. CLIMATE CHANGE IN NEW ZEALAND

At a regional and local scale, modelling climate interactions accurately becomes more difficult because of the need to consider factors such as local topography, wind patterns, land-use and altitude. A lack of available data, processing power and financial resources makes comprehensive individual local and regional models infeasible at present (Ridgen, 2002). Instead, the National Institute of Water and Atmospheric Research (NIWA) apply statistical downscaling techniques to enable the use of GCM projections on a smaller scale (Mullan and Renwick, 1990). Table 1 illustrates annual mean temperature and precipitation changes for the major New Zealand districts as projected using GCM scenarios assuming no attempts to control greenhouse gas emissions in the future. Under this scenario, atmospheric carbon dioxide is expected to reach a concentration of 700ppm by 2100, approximately double present levels (MfE, 2001).

**Table 1**  
Projected changes in annual mean temperature and precipitation in New Zealand for the period 2070-2099 relative to the period 1970-1999 (MfE, 2001)

Region	Temperature	Precipitation
Northland, Auckland	+1.0° to +2.8°C	-10% to 0%
Western North Island from Waikato to Wellington	+0.8° to +2.7°C	0% to +20%
Eastern North Island from Bay of Plenty to Wairarapa	+0.9° to +2.7°C	-20% to 0%
Nelson, Marlborough, to coastal Canterbury and Otago	+0.8° to +2.5°C	-20% to +5%
West Coast and Canterbury foothills	+0.6° to +2.5°C	+5% to +25%
Southland and	+0.6° to	0% to

inland Otago	+2.2°C	+30%
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In general, New Zealand is likely to warm by only two-thirds of the global mean temperature increase thanks to the moderating influence of its ocean surrounds. Projections for sea-level rise are more uncertain due to the influence of natural climate variations (such as the El Niño Southern Oscillation and Interdecadal Pacific Oscillation phenomena), earthquakes and gradual tectonic uplift and subsidence, although it is likely that mean sea-levels will rise between 5 and 66cm by 2100, with an IPCC worst case of up to 84cm. Sea-levels are projected to rise at a rate between one and four times as fast as they did during the last century. However no significant trend has yet been confirmed in New Zealand (MfE, 2001). This is not unexpected, as it is estimated that at least 20 years of measured increase is required before it may be stated with certainty that sea-level rise is accelerating. This is largely due to the masking effects of the El Niño Southern Oscillation and Interdecadal Pacific Oscillation phenomena (Bell and Salinger, 2002).

projections for changes in the frequency and intensity of extreme climate events are particularly uncertain, unfortunately, as such changes pose a potentially larger threat than gradual climate change. General projections for expected climate change in New Zealand also include (MfE, 2001):

- a faster rate of temperature increase in the North Island than in the South, with a more rapid increase in temperatures during winter than in summer
- an increase in the gradient between precipitation on the west and east coasts, with more rain expected in the west of the country and less in the east
- greater extremes of drying and rainfall intensities, with drought conditions more likely for some eastern regions such as Canterbury and Hawke's Bay
- an intensification of prevailing westerly winds in southern mid- to high latitudes.

#### 4. COASTAL MARGINS

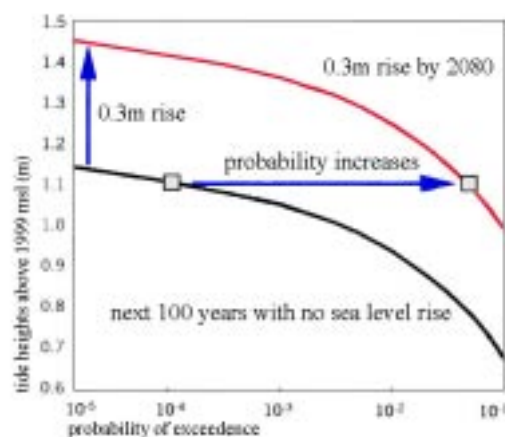
As coasts are particularly dynamic systems, the impacts of climate change on coastal margins may differ markedly between locations. As part of the New Zealand Climate Change Programme, Bell *et*

*al.* (2001) have recently completed an investigation into the effects of climate change on coastal margins in New Zealand. The major physical coastal impacts associated with climate change include (Bell *et al.*, 2001; Tonkin and Taylor, 1999):

- increased coastal inundation, causing landwards displacement of estuaries, wetlands and marshes
- changes in shoreline erosion as equilibrium positions become modified and sediment deposition patterns change
- increased vulnerability to coastal storm damage and episodic flooding
- the possibility of increased sediment load to estuaries, with projected increases in rainfall intensity and run-off
- increased difficulty in draining coastal and river lowlands
- increased saltwater intrusion of river water and groundwater in low-lying coastal areas.

#### Sea-level Rise and Coastal Inundation

Any increase in mean sea level will increase the likelihood and extent of coastal flooding by extreme tides and storm surges, in addition to causing permanent inundation in some areas. Increases in storm surges and intensities will only serve to compound this effect (Bell *et al.*, 2001). As this sea level rises, so too does the probability of a given land level being exceeded. A study of tidal heights for a gauge at Moturiki (Bay of Plenty) found that, assuming a nominal increase in mean sea level (MSL), the probability of a tide exceeding a point 1.1m above the 1999 MSL in the next 100 years would increase from 0.01% (present) to 5% (Figure 1) (MfE, 2001).



**Figure 1** The effects of sea-level rise on exceedence probabilities at Moturiki (MfE, 2001) Unfortunately, predicting changes in the return periods of extreme flood events from observations recorded over limited time-spans is particularly difficult. For example, it may take 50 years of observations to statistically establish whether a 100-year return period event is occurring more frequently (e.g. every 25 years). Therefore, significant damage may be caused as a result of reduced flood-return periods before any such change can be statistically proven (MfE, 2001). This difficulty underlines the requirement for a precautionary approach when planning for the effects of climate.

Any increase in sea level is particularly relevant for developed coastal margins, because the landward migration of the shoreline may be blocked by human land-uses and infrastructure. 'Coastal squeeze' is likely to occur in many developed areas as low-tide levels continue to rise while high-tide levels are constrained by stop-banks and sea-walls, resulting in a loss of inter-tidal areas (Bell *et al.*, 2001). This may adversely affect both natural ecosystems and access to traditional Maori food-gathering grounds and waahi tapu. Maori, with their affinity to both the land and the sea, are particularly sensitive to any loss of land as a result of flooding or erosion (Bell *et al.*, 2001). Additionally, this loss of inter-tidal areas may greatly reduce the natural buffering capacity provided by the coastal environment. This would be further compounded by any increase in storm frequency or intensity (Green, 1999).

Due to a lack of long-term tidal records for New Zealand, no comprehensive analysis of the expected frequency of sea-defence breaches in the case of increased sea-levels has been carried out. Such analysis would be complicated by the fact that an increase in average sea-level may not necessarily lead to corresponding changes in maximum tidal heights, as currents, wave patterns and morphological changes (e.g. spits and sandbars) may alter the propagation of local tidal waves (MfE, 2001). In some instances, increased sediment supply to coastal margins caused by higher-intensity rainfalls may serve to counteract sea-level rise due to increased coastal sediment deposition in estuarine areas (Bell *et al.*, 2001). To date, sedimentation in New Zealand's estuaries has

kept up with the present sea-level rise of approximately 1.8mm/yr, although it is unclear what the long-term tidal prism effects may be. In accordance with the precautionary principle, it should be assumed that tidal prism volumes will eventually increase (Bell *et al.*, 2001).

## Erosion

Shoreline erosion and sediment deposition allow coastal systems to act as buffers between the land and ocean environments. The specific responses of a shoreline to changes in climate will depend on the local physical characteristics.

Higher precipitation intensities are generally expected to increase erosion risk (MfE, 2001). Within coastal margins, sea-level rise will be a major cause of increased erosion. Additional erosion-inducing factors associated with climate change include (Bell *et al.*, 2001):

- effects on sediment deposition and transportation
- any long-term change in the approach angle of the predominant wave action to the shoreline
- effects on the natural vegetation growth and corresponding effects on dune stability
- any effects on sediment supply from offshore, rivers and cliff erosion.

It is important that the diverse impacts of climate change on the coastal environment are not considered in isolation from one another. Quantitative assessments of coastal impacts require localised studies incorporating sea-level rise, erosion, shoreline characteristics, changes in wave climate, sediment supply and storm patterns so as to provide an integrated assessment. Engineers are likely to have a significant role to play in completing such assessments.

## The Engineering Response

The diverse impacts of climate change on the coastal environment will require engineers to implement a diverse range of responses. These responses may be categorised as (Bell *et al.*, 2001):

- planned retreat
- adaptation/accommodation
- protection/defence.

Planned retreat involves the progressive movement of developments away from the coast. It is a particularly cost-effective option for undeveloped coastal areas where the high capital and maintenance costs of protection works cannot be justified. Where erosion and inundation are already posing threats to coastal developments, planned retreat may be the only viable long-term response as adaptation and protection measures become prohibitively expensive. Planned retreat also entails the prevention of future development along the threatened coast (Bell *et al.*, 2001).

Adaptation mechanisms seek to adjust land-use in order to accommodate coastal impacts. Because the dynamic coastal environment is so complex, adaptive measures must be 'appropriate' (i.e. applied within a specific context). Adaptive engineering responses to the projected impacts of climate change on coastal margins include (Ridgen, 2002; Bell *et al.*, 2001):

- the elevation of existing roads, railways and buildings
- the installation of additional drainage pump stations in response to changes in hydraulic head caused by sea-level rise and precipitation changes
- the enhancement of vegetation cover on sand dunes to help resist erosion
- planting of wetlands, upper-tidal and salt-marsh environments in order to maintain estuarine ecosystems
- moving towards land-use practices that are more adaptable or less vulnerable to climate change (e.g. salt-tolerant crops, 'greenfields' developments).

Hard coastal protection works (e.g. groynes, breakwaters, sea-walls) may require significant capital and maintenance expenditure, and may damage the aesthetic character of the coast and restricting coastal access (Pilkey and Hume, 2001). Furthermore, the protection offered by such engineering structures is often of limited duration as 'coastal squeeze' reduces the natural buffering capacity of the coast, causing increased exposure to the dynamic ocean environment and resulting in rapid structural degradation. Hard protection works may be justified only in instances where the land at risk is of high value, particularly in heavily

developed urban areas (Bell *et al.*, 2001). Soft protection measures such as beach nourishment and vegetation plantations may be considered more sustainable as they protect both the built environment and the natural buffering capacity of the coast.

The successful management of the impacts of climate change on coastal margins requires the implementation of a variety of complementary responses. Where possible, the management approach should be integrated so as to co-ordinate coastal development in a complementary manner. For example, dredgings removed as part of a new development should be made available for coastal nourishment schemes to offset any adverse effects that the dredging may have had on the regional sand budget (Bell *et al.*, 2001). While continuing to provide innovative, cost-effective, adaptive and protective solutions to the physical problems posed by climate change, engineers must take a proactive approach to driving this essential integration by applying their multi-disciplinary and managerial skills.

## 5. HUMAN SETTLEMENTS AND INFRASTRUCTURE

The most significant climatic impacts on the built environment are likely to be associated with any increase in frequency or intensity of extreme events, including flooding. More accurate research into changes in tropical cyclone patterns is urgently required because any increase in such events is potentially devastating (Camilleri, 2000).

The natural variability in the New Zealand climate means that infrastructure is already designed to withstand climatic extremes to some extent. However, possible increases in the frequency or intensity of these events may place the built environment under significant stress. The long-distance nature of New Zealand's infrastructure, a result of the relatively low population density, makes it particularly vulnerable to climate change as it is difficult and expensive to protect and maintain (MfE, 2002). Furthermore, infrastructure tends to be particularly vulnerable to flooding as many network services are located underground or on cheaper undeveloped land along creeks and water courses (Minnery and Smith, 1996). Although

the impacts of climate change on the urban environment are important, they are likely to be exceeded in significance by economic, population, pollution and transportation management influences (MfE, 2001; Green, 1999).

## Precipitation

Expected increases in the frequency and severity of inland flood events as a result of precipitation changes will result in increased damage to buildings, drains, roads, bridges, cables and other infrastructure. Drainage networks, particularly urban stormwater systems, may be unable to cope with the increased run-off likely to result from increased rainfall intensities (Mosley, 1990). If sewerage and stormwater networks are unable to cope with increased run-off, overflow discharges may contribute to surface flooding. Contamination by sewage may occur more frequently as a result of increased infiltration and overloading (Griffiths, 1990). Increased precipitation may also increase the rate of leachate production and surface run-off from landfills (Mosley, 1990). Greater erosion in response to increased rainfall intensities may threaten the built environment with a higher risk of landslips and rock-falls, as soils have less time to drain and recover between more frequent high-intensity events (Camilleri, 2000).

## Sea-level Rise and Changes in Groundwater Levels

Sea-level rise may adversely affect the built environment by increasing shoreline retreat, storm surge and tidal inundation, in addition to presenting drainage problems for aquifers in low-lying areas with low hydraulic head (e.g. Christchurch) (MfE, 2001). Developed sheltered coasts may be more vulnerable to sea-level rise, as houses are built close to the shoreline without a large margin for storm surge and waves. On exposed coasts, storm waves are likely to be more influential than sea-level rise (Camilleri, 2000).

Building foundations in low-lying areas may suffer damage as a result of more frequent flooding and changes in groundwater pressure, particularly in areas with high water tables (Camilleri, 2000). The cost of damage to buildings is expected to equal or exceed any changes in flooding Annual Exceedence Probabilities (AEPs), with a fourfold

increase in AEP resulting in up to a tenfold increase in the cost of building damage (Camilleri, 2000).

Changes in groundwater levels may also damage drainage network and septic tank operations due to changes in groundwater pressure beyond design specifications. This may have negative public health effects, especially if groundwater wells become contaminated (Mosley, 1990). Sea-level changes may also alter pressures within stormwater and sewerage systems. For this reason, urban drainage engineers have identified sea-level rise as an area of particular concern. Sea-level rise may also pose a threat to wastewater treatment facilities (e.g. oxidation ponds) located on the coast (Mosley, 1990).

## Flood Management

Recent research undertaken by the Building Research Association of New Zealand (BRANZ) into the impacts of climate change on houses and office buildings has identified flooding as the issue requiring most urgent action (Camilleri, 2000). Flooding already presents a significant risk to many settlements in New Zealand. It has been estimated that \$880 million in assets will be placed at risk from a 1:100 year tidal event if the Christchurch sea-level rises by 0.5m by 2100 (Tonkin and Taylor, 1999).

In addition to the general coastal responses explored earlier, strategies for reducing the risk and impact of flooding on the built environment include (Camilleri, 2000):

- reducing the risk of flooding;
- reducing the damage potential of flooding to buildings, contents and infrastructure;
- improving the ability to recover from flooding;
- being prepared for floods.

As buildings and infrastructure now being constructed have projected lives to at least 2050, it is important that consideration be given to changes in climate that may occur over the lifetime of the structure (McCarthy *et al.*, 2001). Regarding flood damage in particular, it is likely to be more economical to design human settlements for the future than to adapt existing settlements in the face of climate change. A precautionary approach is essential because significant damage may occur

during the time it takes to statistically verify any change in flood return period (Camilleri, 2000). Climate change requires that engineers use a great deal of foresight when designing and building new developments.

Flood management measures commonly used to mitigate impacts on the built environment include (Mosley, 1990):

- assessment and re-evaluation of flood hazards, management plans and flood-plain zones;
- increased monitoring of water levels for planning and design purposes;
- enhanced flood warning systems;
- repair, maintenance and upgrading of existing flood-protection structures;
- installation of new flood-protection structures;
- retreat from currently protected regions as continued flood protection becomes uneconomic;
- greater expenditure on emergency management and disaster relief.

All of these options must be pursued to various extents in order to provide an integrated and comprehensive approach to flood management in response to the impacts of climate change. With regards to the construction of new developments, primary priorities include the assessment of flood risk and the avoidance of construction on a flood-prone site (Camilleri, 2001). This may be achieved by strengthening current policy measures (Ridgen, 2002). Engineers have a role to play in the regional (primarily) and territorial management of flood risk as both expert advisors and participants in the policy development process. In particular, engineers must be involved in the regional and local assessment of flood risk and the development of sufficiently precautionary flood hazard zones. Due to the high level of uncertainty and the length of period over which that uncertainty applies, a suitable precautionary approach may be to assume and plan for changes in flood level and frequency of a magnitude double those predicted by current climate scenarios.

### **Drainage Networks**

Engineers also have an important role to play in implementing physical mechanisms designed to

reduce the impacts of climate change on the built environment. Drainage and sewerage networks may need to be modified or re-designed in order to accommodate precipitation events of increased intensity (i.e. higher peak flows), infiltration and pressure changes induced by sea-level rise. Pumping stations may also be required in order to ensure the continued operation of existing networks, particularly in the low-head aquifers of the Canterbury region. Costs associated with the upgrade of existing drainage infrastructure are substantial and engineers must consider climate change projections when designing future systems (Mosley, 1990). An example of a precautionary approach to stormwater and wastewater system design is that of Wanganui District Council. Projected regional rainfall trends caused by climate change were evaluated and this information was then used to design the capacity of the pipe network and the soak-pits required to accommodate any increased run-off (ARC, 2002). Where possible, critical infrastructure should be relocated to areas of lesser risk to flooding and sea-level rise (Ridgen, 2002).

Wastewater facilities in coastal areas such as oxidation ponds may require increased protection from erosion, sea-level rise or even relocation. Septic tank requirements may also have to be improved in order to prevent leakage and contamination. However, costs associated with the impact of climate change on wastewater treatment and disposal are likely to be less significant than factors such as technological capabilities and institutional arrangements (Mosley, 1990).

### **Additional Engineering Responses**

Additional engineering responses to the impacts of climate change on the built environment include (Camilleri, 2001):

- the construction of small-scale flood-protection works (e.g. levees, flood-walls);
- relocating or raising buildings;
- flood-proofing, using water-resistant materials (e.g. concrete block, fibre-cement) and precautionary design (e.g. the installation of vulnerable building services at a higher level);
- increasing minimum floor levels;
- multi-storey construction, with the first storey used as a non-living space (or in office

- buildings, the location of valuable and essential services above ground level);
- improved utilisation of effective thermal design (e.g. passive solar) in response to increased mean temperatures;
- strengthening and designing bridges to accommodate increased river flows during periods of flooding;
- relocating or strengthening coastal roads and infrastructure in response to an increased risk of erosion and inundation (e.g. Kaikoura Coast);
- increasing design consideration of the changes in wind conditions on building loadings;
- increasing design consideration of a greater risk of landslips, rock-falls and erosion caused by increased rainfall intensities.

It must be noted that many significant impacts of climate change on human settlements will be associated with the mitigation of greenhouse gas emissions. For example, future urban planning is likely to be focussed around public transport networks that reduce the need for automobiles. Engineers will be expected to produce designs and technology that are more energy efficient and less reliant on fossil fuel energy sources. These issues can be expected to have an increasing influence on the engineering discipline; however, they were considered beyond the scope of this research.

## 6. WATER RESOURCES AND HYDROLOGY

Climate change is likely to alter the spatial and temporal patterns of precipitation in New Zealand (Griffiths, 1990). Decreased precipitation and increased mean temperatures, particularly in eastern regions (e.g. Canterbury, Hawke's Bay), will reduce the availability of water and increase the severity of drought. This is likely to be exacerbated by expected increases in urban and agricultural demands (MfE, 2001).

Estimates for the likely changes in New Zealand run-off flows for the most recent climate change scenarios have yet to be published, although run-off is expected to decrease significantly in eastern regions (MfE, 2001). Expected increases in rainfall intensities may lead to higher concentrations of suspended solids and other contaminants in surface run-off (ARC, 2002). Increased sediment loadings may reduce reservoir and flood storage

capacities, in addition to reducing water quality for agricultural, industrial and domestic use (Griffiths, 1990).

Sea-level rise may cause saltwater intrusion into coastal aquifers, with adverse effects for lowland coastal bore-water supplies. The inland migration of the saltwater/freshwater interface is likely to be exacerbated by continued bore extraction and any reductions in groundwater recharge (Griffiths, 1990). Excessive pumping for agricultural and urban requirements, in conjunction with sea-level rise, may even induce some aquifers (e.g. Christchurch) to reverse flow direction (Bell *et al.*, 2001). Inland saltwater migration may also cause vegetation dieback and a breakdown in soil structure. A case study of the Lower Avon and Heathcote Rivers in Christchurch identified a possible bank collapse of 10m as a result of this effect (Tonkin and Taylor, 1999). The extent of saltwater intrusion will be dependent on local soil characteristics.

Positive impacts of climate change include more secure water supply in western and northern regions and beneficial changes to seasonal river flows for hydro-electricity generation in the South Island (MfE, 2001). Snowlines and glaciers are expected to retreat as a result of global warming, and this is likely to result in more flow in winter (as precipitation is no longer stored as ice and snow-pack) and less in summer (due to reduced melt material). These changes in seasonal river flows are likely to have significant impacts on hydro-electricity storage and generation, particularly in the South Island. At present, river inflow to hydro-catchments in the South Island is lowest during winter, when electricity demand (for heating) is the highest, with inflow increasing during spring and summer as the snow-pack begins to melt. Projected increases in precipitation in the Main Divide during winter, in conjunction with warmer average temperatures causing electricity demand reductions, would suggest that climate change may be beneficial as regards hydro-electricity supply (MfE, 2001). These benefits may be offset to a limited extent by an increase in summer electricity demand for air conditioning and an increase in flooding damage to hydro-electric schemes (MfE, 2001).

## The Engineering Response

When planning for future water resource problems, a flexible approach is necessary. Adaptation and adjustment mechanisms for implementation in response to climate change in New Zealand include (Griffiths, 1990):

- incremental adjustments under current management arrangements;
- changes in management criteria;
- revamping of the system, including the development of major structural solutions.

Incremental adjustments may involve the more stringent application of the traditional approach to water management which relies on the conservative over-design of network capacities as a means of accommodating unexpected events (Griffiths, 1990). Examples of this type of adaptation in the context of climate change might be reducing allowable irrigation abstraction levels, or tighter domestic flow restrictions in response to increased drought risk in eastern regions. This traditional approach has been reasonably successful; however, an active management approach integrating these measures with sustainable land-use practices, voluntary agreements, direct regulation and market mechanisms is likely to offer a more robust approach to the varied impacts of climate change.

Changes in management criteria will also be needed as climatic change occurs. Examples of such changes may include regulations governing specified water use or design features. For example, permeable paving materials or soak pits may become mandatory as mechanisms for improving groundwater recharge in urban areas with limited groundwater supply.

Where the impacts of climate change exceed capacity tolerances in design networks, structural overhaul may be required. This may involve the construction of additional water supply features, including artificial reservoirs, diversionary structures and pipelines from distant water sources. Engineers would be heavily involved in the design of such features.

Other engineering responses to the impacts of climate change on water resources include (ARC, 2002; Green, 1999):

- integrated catchment management;
- strategic and pro-active precautionary planning and management;
- the design and implementation of more water-efficient processes;
- the construction and modification of engineering structures, including the structural strengthening and improvement of reservoir dams to accommodate possible changes in extreme events;
- improved water supply measures, supported by water efficiency initiatives and pricing systems;
- the monitoring and evaluation of sedimentation in waterways and reservoirs.

Integrated catchment management involves applying various complementary physical, regulatory, economic and strategic mechanisms. It is likely to be a particularly effective means of managing the impacts of climate change on water resources in New Zealand, as it is both flexible and robust. This approach is particularly reliant on strategic policy and planning. Engineers have an important role to play in the formulation of strategic regional water management policy as expert advisors, researchers, monitors and managers. Engineers must also be actively involved in establishing the vulnerabilities of systems to climate change, assessing the extent to which the critical features of a given flow regime can change before that system becomes critically stressed (McCarthy *et al.*, 2001). Regarding water resources, climate change requires the continued participation of engineers in both the design and implementation of physical and managerial mechanisms and the development of integrated catchment management policy.

## 7. ACTING ON CLIMATE CHANGE

In New Zealand, natural hazard planning and management is conducted largely under the umbrella of the 1991 Resource Management Act (RMA). Under this hierarchical framework, there are various statutory instruments for planning for, managing and mitigating the impacts of natural hazards. Implicitly, hazards associated with climate change may be considered within this framework, in which consideration of future climate change may be explicitly or implicitly provided for in plans and policy statements (Bell *et al.*, 2001). In this regard,

New Zealand may be considered fortunate in that it has an existing legislative framework that may be extended to encompass issues pertaining specifically to climate change. For example, the 10-year review period for water allocations under Regional Plans may be considered an effective adaptation mechanism as regards climate change (McCarthy *et al.*, 2001).

Central government has an important role in providing guidance, leadership and information regarding planning for the impacts of climate change. To date, much of the work of the Ministry for the Environment has focused on reducing greenhouse gas emissions rather than on adaptive responses to climate change (ARC, 2002). However, under the RMA, it is largely the responsibility of regional authorities to avoid or mitigate natural hazards. In this respect, engineering action on climate change is likely to be primarily at a regional level.

However, the relevant roles and appropriate responses for local government have yet to be clearly defined by the Ministry for the Environment (ARC, 2002). As a result, the current approaches to planning for the impacts of climate change vary among the numerous regional councils and territorial authorities. Recent surveys of the responses of local bodies to sea-level rise have highlighted this lack of uniformity, with little similarity in projections, safety margins and planning horizons (Bell *et al.*, 2001; Tonkin and Taylor, 1999). At present, planning for climate change at the regional level has been restricted largely to the use of precautionary language, rather than specific policies and requirements (Bell *et al.*, 2001). Although an analysis of the required responses of central and local government to the impacts of climate change was beyond the scope of this research, engineers must recognise that improvements in this area are essential if such responses are to be implemented effectively.

### **Integrated and Sustainable Management**

Many of the managerial mechanisms that should be implemented in response to climate change are likely to benefit all stakeholders in the long term. Many of the required adaptations also make good sense given present-day climatic variability and extremes such as droughts and floods (Green,

1999). The challenges posed by the need to integrate complementary physical, managerial and political responses are common to both climate change and sustainable management. While these challenges are certainly substantial, steps taken towards addressing them will go a long way towards ensuring a more sustainable future.

## **8. CONCLUSIONS**

The diversity of the impacts of climate change in New Zealand requires the integration and implementation of a wide range of physical and managerial measures, which must be supported by precautionary and strategic policy. The need to operate in a precautionary paradigm, because of the gradual nature of climate change and the high levels of uncertainty of climate projections, must be acknowledged and adopted by the modern engineer. Quantitative regional climate-change hazard assessments provide an important basis for such a precautionary approach and engineers are likely to be heavily involved in the completion of these assessments in the future.

Coastal margins, human settlements, infrastructure and water resources are all vulnerable to climate change, particularly increased flooding, higher precipitation intensities and sea-level rise. In the dynamic coastal environment, the impacts of climate change will require the integration and implementation of a range of planned retreat, adaptation and protection mechanisms.

The most significant impacts of climate change on the built environment are likely to be associated with any changes in the frequency or intensity of extreme events, particularly flooding. A wide range of physical responses must be implemented in conjunction with strategic policy, with a focus on developing sufficiently precautionary flood management plans and drainage network modifications.

Regarding the impacts of climate change on water resources, physical engineering responses must be implemented in conjunction with managerial responses such as incremental progressive system adjustments, changes in management criteria and major system restructuring. Integrated catchment management is likely to be the most effective

means of managing the impacts of climate change on water resources.

With their multi-disciplinary, technical and managerial skills, engineers are ideally placed to contribute significantly towards managing the impacts of climate change in New Zealand. While continuing to provide innovative and appropriate solutions, engineers have an important role to play in driving the integration of action and policy that is so essential if the impacts of climate change are to be managed effectively. In this regard, steps taken towards addressing the challenges associated with climate change will go a long way towards ensuring a more sustainable future.

## 9. REFERENCES

- Auckland Regional Council (ARC), 2002. *The impact of predicted climate change on hazards in the Auckland Region – Scoping study*, Working Report No. 94, (Auckland Regional Council)
- Bell, R G and Salinger, M J, 2002. Coast under threat from rising seas, *New Zealand Herald*. 14 August 2002.
- Bell, R G, Hume, T M and Hicks, D M, 2001. *Planning for Climate Change Effects on Coastal Margins* (Wellington: Ministry for the Environment).
- Camilleri, M J, 2001. *Implications of Climate Change for the Construction Sector: Adaptation and Mitigation Strategies*, Building Research Association of New Zealand, Study Report SR107 (Wellington: BRANZ Ltd).
- Camilleri, M J, 2000. *Implications of Climate Change for the Construction Sector: Houses*, Building Research Association of New Zealand, Study Report SR94 (Wellington: BRANZ Ltd).
- Fenwick, R, Silyn-Roberts, H and Boyle, C A, 1998. Should engineers be concerned with climate change? *IPENZ Transactions*, 25(1/GEN):1-10.
- Green, M, 1999. *Climate Change: a brief review*, Publication No. WRC/RP-G-99/8 (Wellington Regional Council)
- Griffiths, G A, 1990. Water Resources, in *Climatic Change: Impacts on New Zealand*, pp 38-43 (Wellington: Ministry for the Environment)
- Houghton, J T et al., 2001. *Climate Change 2001: The Scientific Basis* (Cambridge University Press).
- McCarthy, J J et al., 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (Cambridge University Press).
- Ministry for the Environment (MfE), 2002. *National Communication 2001: New Zealand's Third National Communication under the Framework Convention on Climate Change* (Wellington: Ministry for the Environment).
- Ministry for the Environment (MfE), 2001. *Climate Change Impacts on New Zealand* (Wellington: Ministry for the Environment).
- Minnery, J R and Smith D I, 1996. Climate Change, Flooding and Urban Infrastructure, in *Greenhouse: Coping with climate change* (Eds: W J Bouma, G I Pearman and M R Manning), pp 235-47 (Melbourne: CSIRO Publishing).
- Mosley, M P, 1990. Water Industry, in *Climatic Change: Impacts on New Zealand*, pp 133-39 (Wellington: Ministry for the Environment)
- Mullan, A B and Renwick, J A, 1990. *Climate change in the New Zealand region inferred from general circulation models* (Wellington: New Zealand Meteorological Service).
- Pilkey, O H and Hume, T, 2001. The shoreline erosion problem: lessons from the past, *Water and Atmosphere*, 9(2)22-23. Also available [Online]: <http://www.niwa.cri.co.nz/pubs/wa/09-2/erosion.htm>
- Ridgen, J, 2002. *Impacts of Climate Change on Christchurch*, Technical Report 02/1 (Christchurch City Council: Christchurch). Also available [Online]: <http://www.ccc.govt.nz/Reports/2002/ClimateChange/ClimateChange.pdf>
- Tonkin and Taylor, 1999. *Christchurch City Council: Study of the Effects of Sea Level Rise for Christchurch* (Christchurch: Tonkin and Taylor).

