THE IMPLICATIONS OF CLIMATE CHANGE ON ROAD INFRASTRUCTURE PLANNING, DESIGN AND MANAGEMENT

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Abstract

There is widespread discussion about the impact of climate change on coastal environments and the anticipated rise in sea levels. Our involvement in the road industry, whether we be in planning, approval, design, asset management or construction, requires us to be planning practical measures to manage the effects of climate change from a transport and social responsibility perspective.

This paper presents a discussion about the impact of climate change and sea level rises on road infrastructure and what measures could be considered to mitigate or alleviate potential impacts. The paper is focused on road assets but the impacts and considerations are common over a range of coastal planning issues and other infrastructure asset areas.

Introduction

There is widespread discussion about the impact of climate change on coastal environments and the anticipated rise in sea levels. This paper presents a discussion about the impact of climate change and sea level rises on road infrastructure and what measures could be considered to manage potential impacts. The paper aims to achieve this by:

- Summarising information about the known behaviour of pavement materials subjected to various environmental conditions;
- Outline issues surrounding the planning and design of road infrastructure; and
- Present examples of how these should be considered in the context of the road industry.

Mills and Audrey (2002) present three transportation sensitivities associated with climate change. These are:

- Infrastructure (Including roads): Comprising planning and design, construction and maintenance;
- Operations: Efficiency, mobility, safety, and environment and social externalities; and
- Demand: that includes location, timing, mode(s) and sector.

This paper will primarily focus on the planning and design of road infrastructure and impacts to road materials as a result of climate change. In consideration of this, there are a number of questions to be considered by the climate change scenario, namely, What are the implications of rising water, salinity and temperatures levels on pavement materials? Do current design practices build in appropriate redundancy to road and infrastructure assets to cope with anticipated effects? What impacts will these elements have on strategic transport networks and how can impacts be managed from an asset management planning perspective? Importantly, what should we be doing now to prepare for the impacts of climate change on our road assets?

Why Bother?

Our involvement in the road industry, whether we be in planning, approval, design, asset management or construction, requires us to be planning practical measures to manage the effects of climate change from a transport and social responsibility perspective. From an engineer's perspective, the implementation of technical solutions to meet societal and economical demands places us at the centre to managing the effects of climate change and to be at the forefront of providing a framework for climate change strategy. Climate change will have wide-ranging effects on our society and will require a multi-faceted approach involving a range of skills from planning, design, construction and management to best manage this issue.

Background to Climate Change and Anticipated Effects

The fact that climate change is occurring and that human activity is contributing to the effect is widely acknowledged in the scientific community. This paper is based on the findings and reported anticipated effects of climate change as stated by the United Nations Intergovernmental Panel on Climate Change (IPCC) (2001) and various commentaries provided by the CSIRO (2001 and 2007) on specific effects concerning Australia. The prediction of effects is complex, involves numerous uncertainties and assumptions and accounts for a range of emissions scenarios. However, recent data seems to suggest the IPCC predictions may understate some outcomes, such as the likely rise in sea level over the next century. For the purposes of this paper, the published information from the IPCC report forms the basis of discussions and can be summarised as follows:

- 0.09 to 0.88m sea level rise (central value 0.48m), which is up to 8.0cm per decade;
- Annual temperatures will increase by 2 to 6 degrees celsius by 2100 with more extreme hot days. Recently published reports from the CSIRO (2007) indicate a 4.3 degree Celsius increase by 2070;
- Forecast for general reduction in rainfall over most of Australia except in the far north where significant increases will occur;
- Higher frequency of droughts in regions where average rainfall decreases and more extreme wet years where it increases;
- Projected increase in evaporation over most of the country; and
- Expected increase in frequency and severity of extreme weather events and possible poleward range expansion of cyclonic events.

In terms of road infrastructure, these translate to direct impacts as follows:

- Extreme maximum temperatures and length of hot spells;
- Annual rainfall (reduction);
- Extreme rainfall events, influencing flood levels and potentially frequency of flooding;
- Available moisture (evaporation and rates of rainfall);
- Wet and dry cycles: affecting water tables and surface and subsoil inundation cycles;
- Rising levels of salinity (primarily inland but also affecting coastal areas); and
- Sea level rise.

The question then arises, how do these impacts relate to roads and what should we be doing, if anything, to accommodate them?

Road Materials

Road pavements comprise various layers of materials that act together to provide a defined level of service depending on the traffic volumes and vehicle types. The pavement layers are generally thicker in the lower levels and consist of granular, stabilised, or cementitious materials with granular being the most widely used and economical of these. Stabilised or bound (concrete, lime, etc) base layers are generally used for higher strength pavements or for specialised applications such as pavements subject to water inundation during construction or frequent wetting and drying cycles. The upper pavement layers can comprise several layers of bituminous materials for heavy-duty pavements or a single thin surface of bitumen for lighter pavements. Concrete pavements are common for long-life, high load/volume arterial roads and specialist applications. Quite obviously, major arterial roads are commonly thicker and use more expensive materials than lower order roads. For example, the Pacific Highway (heavy duty pavement) as compared to local roads in residential areas.

Bituminous pavements are typically designed for a 20-year lifespan and concrete pavements for 40 years.

Temperature Effects

Pavements are designed for a wide range of climates in Australia, from the colder alpine areas to the semi-arid and arid regions. Climate change will effect the selection and specification of pavement materials and will influence asset management strategies. Over a period of say, several decades, temperature rises are likely to change the use of materials, particularly those that are temperature sensitive, eg bitumen based. These changes are expected to be gradual and manageable.

Higher temperatures are expected to result in the need for increased frequency of resealing/resurfacing due to the more rapid oxidation of the bitumen. In the design of thick asphalt pavements, the asphalt is characterised in terms of its stiffness at weighted mean annual pavement temperature (WMAPT) for the location. The higher the WMAPT, the less stiff asphalt. Therefore we expect that climate change may result WMAPT increasing in some areas, resulting in thicker asphalt to accommodate the lowering of the asphalt stiffness. This applies to deep strength asphalt pavements for heavy duty (eg highway) applications.

Pavements subject to low speed turning movements can lead to high shearing forces on pavements, especially when combined with heavy vehicle loads. Higher temperatures combined with the effects of shearing forces on pavement surfaces may require wearing courses/surfacings to utilise more expensive polymer modified bitumens, rather than conventional bitumen, in a greater number of situations (eg roundabouts, industrial sites etc).

Moisture Effects

Granular materials are the predominant pavement material for the lower pavement layers. These materials perform poorly under the effects of water and pavements with these materials are likely to be vulnerable to rising water tables or water levels in coastal areas corresponding to sea level rise. Frequent cycles of wetting and drying will also limit performance of granular pavement layers. Both of these impacts are likely to occur in many areas due to climate change. This could warrant the use of more bound/stabilised materials in pavements or higher fills to lift pavements above the effects of the ground water. These remedies may not be feasible in many situations, particularly urban environments where property impacts can be prohibitive and where the majority of high volume arterial roads are located. Bound/stabilised materials are more expensive than granular materials.

It is possible that decreasing rainfall could prove beneficial to the life of granular pavement materials due to reduction of wet and dry cycles. However this could be offset from the increasing frequency and severity of storm and rainfall events.

Salinity Effects

The use of saline water during construction (i.e. due to drought) could result in the accumulation of salt in pavement materials during compaction of granular basecourses that could prevent spray seals adhering to the underlying pavement layers. Pavements typically have a spray seal layer between bituminous and other pavement materials. This lack of adhesion has been experienced with some bore waters in the semi-arid and arid zones of Australia and although primarily an inland issue where fresh water can be scarce, there could be coastal environments where these effects could occur. The presence of salt could also exacerbate the shrink/swell behaviour in clay subgrade and fill materials causing more edge cracking of sealed surfaces and resulting in more frequent maintenance activities.

Summary

Pavements are typically designed for a 20 year design life. Under these timeframes, and in consideration of the gradual nature of anticipated climate change effects, it can be expected that normal maintenance activities and reconstruction of pavements will allow management and adaptation to climate change. However, modification of materials or maintenance practices may be required. The primary conclusion is that available road materials are likely to provide sufficient flexibility to accommodate expected climate change impacts, however, construction costs are likely to increase across the sector as higher quality materials or thicker pavements are necessary and/or more frequent maintenance is required for road assets.

Impact to Planning and Design of Road Infrastructure

For many coastal communities, the primary, and sometimes only access can be relatively low-lying and located adjacent to rivers or the ocean and typically has bridge structures. In this context, there is potential vulnerability of these communities to the anticipated impact to climate change, especially due to the predicted rise in sea levels.

Do we understand the magnitude of impacts on road infrastructure at particular locations? Should we be considering what these impacts might have on essential infrastructure and access routes for these communities? Areas that are currently flood free could gradually suffer lower flood immunity and shorter flood evacuation times. For areas currently subject to flooding, consequences and frequency are likely to increase. It is likely that we will be able to manage these changes, as they will be gradual but only from a position of understanding of how our critical road infrastructure is likely to be affected. With competing priorities for infrastructure funding it is important we approach decisions concerning climate change and infrastructure investment from an informed position.

As previously stated, road pavements are typically designed for a 20 year lifespan. Concrete pavements associated with heavy duty uses are typically designed for 40 year lifespans. For the majority of roads, these timeframes are generally appropriate to manage the expected effects of climate change.

However, the most direct and consequential impact of climate change is likely to be the rise in sea level, which will directly effect coastal communities and the infrastructure that services them. Rising sea levels, increased storm intensity and storm surge could result in direct and meaningful impacts to road infrastructure in coastal areas, even within the timeframes of the road design life. In a worst-case scenario of 8cm per decade sea level rise, and ignoring the influence of increased rainfall intensity or storm surge, it is relatively simple to demonstrate the direct impact to road infrastructure.

For major highway upgrade projects, there is typically a requirement to provide road flood immunity of at least one lane free from floodwaters in the 100 year storm. In consideration that a road will have a 20 year design life, simplistically, sea level rise could result in a potential 160mm increase in flood levels in immediate coastal areas. This would remove the 100 year flood immunity criteria for many roads designed on this basis, depending on freeboard. For pavements designed for long lifespans (40 years), the impact is more acute by the time the pavement is due for renewal. This situation would be common for many sections of the Pacific Highway and is typical of many roads throughout coastal areas. It should be noted however, that conventional rules dictate an inundation depth of 300mm over roads is appropriate for vehicles to pass flood waters. Therefore, within a 20 year time frame, serviceability would be significantly reduced, but upper limit sea level rises would not necessarily close the transport network. Is this acceptable to the operation of our arterial road network?

Either we accept that:

- Flood immunity diminishes over the life of the pavement and the opportunity to restore a defined immunity condition occurs when the road is raised as part of the reconstruction at the end of pavement life. There will be many cases, especially in urban areas, where the opportunity to raise roads to counteract rising water levels will be restricted, e.g by property impact.; or
- We account for the anticipated increase in the design process, to provide total or partial consideration to sea level rise.

Current policy does not require consideration of climate change effects nor provides consistent direction in this matter. Appropriate decisions will be a balance between cost of construction and security against anticipated sea level rises.

This balance is especially relevant for elements of the road network that have long design lives such as bridges and tunnels. These structures are usually of significant capital cost and can have design lives of up to 100 years. It is almost certain that these structures will be affected by climate change during their lifetimes and given these structures can not be readily modified to account for changing conditions, it is important that potential impacts are understood and appropriately accounted for during the planning and design process.

Whatever the road element, it is important that decision makers have an understanding of possible future impacts of climate change and to consider these in decisions concerning their strategic road networks and assets. Ideally we should identify critical elements of our road assets to be considered for some level of sea level rise immunity and if necessary incorporate these into our strategic planning and asset management plans. This could be a significant undertaking, but without it, we are not in a position to manage possible impacts and our ability to adapt will be reduced by a reactionary policy regime.

Generally there is lack of direction in Australia on what impacts should be considered from rising sea levels. The Queensland Drainage Manual specifies +300mm above Mean High Water Spring (MHWS) when designing drainage structures, which seems appropriate to accommodate sea level change over the life span of drainage structures. In the UK, the Environment Agency has published maps that state the required rise in sea level to be considered for flood assessment purposes. Information of this standard in the Australian context would provide the direction required to those with interests in the provision and management of transportation and infrastructure assets.

An appropriate position may be that the majority of roads can be managed through conventional asset management strategies and adaptability to climate change can be achieved through the renewal of road assets through normal life spans and material specifications with the acceptance of reduced serviceability. Some roads may need mitigation measures sooner than others; flood evacuation routes or major arterials may be examples. For major structures, the significant capital cost and implications of retrofit suggests these structures should be planned and designed to account for climate change and sea level rise. An upper limit prediction of around 0.88m incorporated into the provision of these infrastructure elements would seem appropriate. In these considerations, the costs and benefits should be accounted for in decisions concerning climate change impacts and decisions regarding the mitigation measures.

There are certainly interesting questions to be considered in terms of who pays the cost of these works? Should the cost of new roads be the total responsibility of the developer? How are retrofit works to existing roads to be funded?

An Example of Rising Sea Level Impact

GHD has recently undertaken flood modelling and concept road design for a project investigating flood evacuation routes and isolation times for a NSW coastal community. The consideration of climate change impacts was not part of the project scope. This example is presented to demonstrate how rising sea levels could influence decision making.

The community investigated was a relatively low-lying coastal area along a river estuary and is currently subject to regular flooding in about the 5 year storm event. Sea level and tidal influences play a direct role in the extent of flooding. GHD's brief required the investigation of flooding profiles and road design to upgrade a minor road in an undeveloped area to provide a flood evacuation route for the 5 or 20 year storm event. A secondary route through an urban environment was specified to be raised as much as possible to maximise the evacuation time for part of the community reliant on this route. It was recognised that it would not provide immunity for the 5 year storm event. The basis for assessment of a limiting road level in terms of calculating an evacuation time was 300mm depth of water over the road.

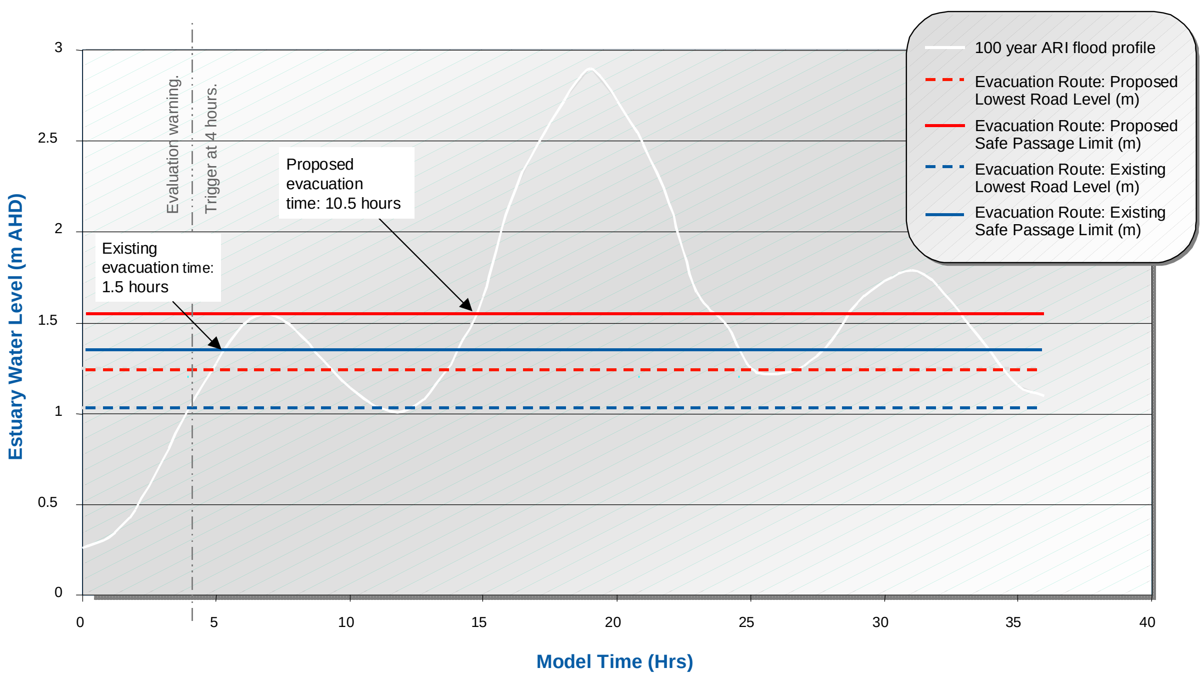
In consideration of the primary flood evacuation route, the 5 year ARI flood level was found to be RL 2.1m AHD and RL 2.4m AHD in the 20 year event. The decision of whether to provide 5 or 20 year flood immunity for the road was to be based on estimated construction costs for each option. Obviously the provision of 20 year flood immunity would be the more expensive option.

With an 8cm increase in sea level per decade, the benefit of the 20 year design level would be eroded within approximately 38 years to 5 year flood immunity. This is a manageable timeframe to adjust to the impact and provides an opportunity for reconstruction within normal timeframes for pavement design life. It would need to be accepted however, that there will be a gradual reduction in the level of service provided by the evacuation route. For 5 year event immunity, it could be expected that rising sea levels will erode flood immunity for all but minor flood events. Again, on the knowledge of reducing standards of serviceability, the road could be reconstructed within normal pavement lifetimes to reinstate immunity levels. However, there is the real possibility that the consideration of climate change impacts may, on balance, make the decision to adopt the more expensive option, i.e. 20 year flood immunity. This issue is currently not a consideration in the decision making process and there seems sound reason for it to be so.

Of critical importance to the success of this project is the provision of road improvements to an existing urban road that serves as the evacuation route for approximately 200 residential properties. The road has numerous low points along its length and the aim was to raise these locations as much as possible to maximise the evacuation time available. The evacuation time is based on 300mm water depth as being safe for the passage of vehicles, which is the generally accepted stability condition in low velocity flow.

Figure 1 shows the flood profiles for the area and the process underlying the decision for an appropriate road level for safe passage during evacuation.

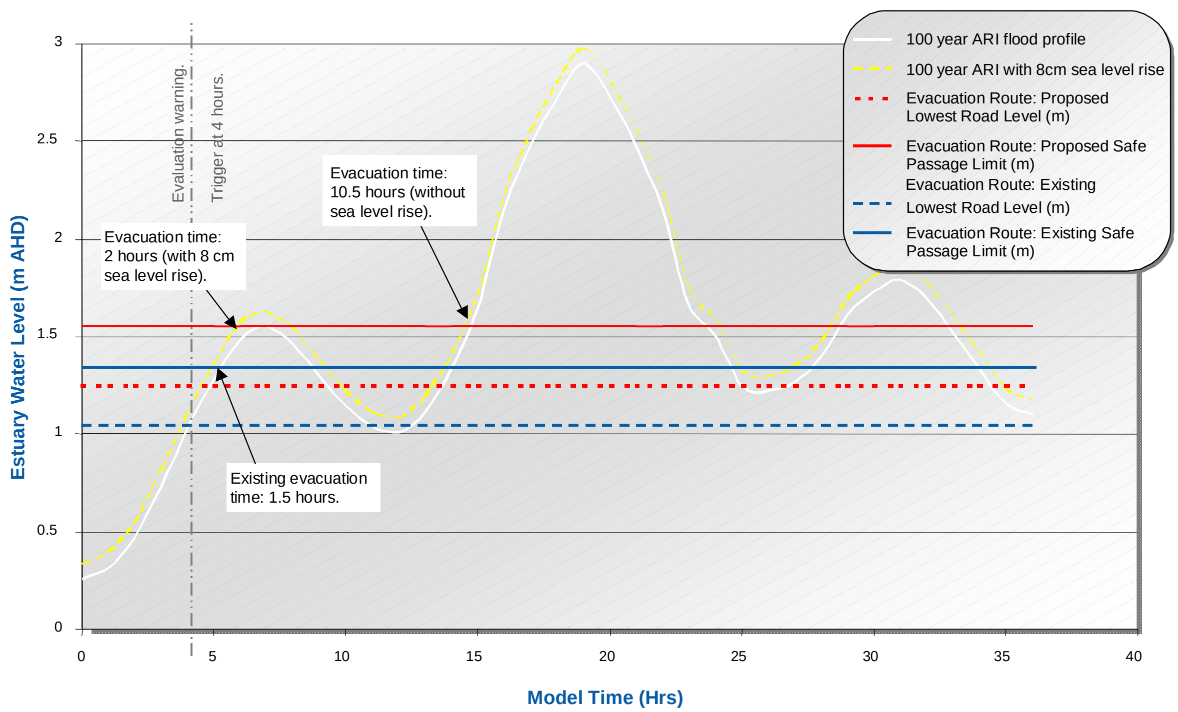
Figure 1 – Evacuation Performance



The council standard for excavation is 8 hours from the warning trigger, which occurs at approximately 4 hours on the profile as shown. The current lowest level of the road is approximately RL 1.03m AHD. By adding the 300mm vehicle stability condition, we arrive at a current safe evacuation level of RL 1.33m AHD, which equates to an evacuation time of 1.5 hours. This does not comply with requirements. For a relatively small increase in road level to RL 1.25m AHD, we are able to achieve safe passage level to RL 1.55m AHD, which allows safe evacuation throughout the first tidal period and on to the second stage tidal surge, providing approximately 10.5 hours evacuation time. This level increase can be achieved reasonably effectively without significant impact on existing properties and infrastructure. Minor drainage problems will be created where some properties are below the road level, however these are manageable with fairly conventional drainage solutions. We believe the need to raise the road more than this will begin to incur higher costs and may not be possible without significant work to raise properties to appropriate levels or provide engineered protection to avoid entrapment of stormwater.

In consideration of rising sea levels, a small increase would raise flood levels that would restrict evacuation to the first tidal surge, resulting in the evacuation time being less than the required time. Figure 2 shows the effect of an 8cm rise in flood level, which could be expected after 10 years if upper bound sea level rises eventuate. Flood evacuation times will be reduced to approximately 2 hours, not meeting the specified time.

Figure 2 – Evacuation Performance with Sea Level Rise



Should sea level rise be considered? If so, the anticipated problems with raising the road further could present significant challenges to providing appropriate flood immunity and evacuation safety to this community. The costs and benefits to provide desired outcomes will place significant pressures on resources should policy be driven by reaction. It may be that acceptance of less desirable outcomes over time is a real possibility for some areas. If sea level rise is not considered, it is possible that meaningful benefits will not be achieved by this project.

Conclusion: Where do we go from here?

The anticipated effects of climate change should be manageable with current engineering practice and the materials available, possibly with adaptation. However, to provide certainty that our road network and transport infrastructure can be properly managed, there needs to be more understanding on what infrastructure is susceptible to the impact of climate change, particularly the predicted rise in sea levels.

The timeframes for pavement materials are suitable to the anticipated gradual effects of climate change, however some constraints and issues exist that warrant consideration of climate change effects for particular projects. Significant capital elements such as bridges and tunnels should accommodate anticipated effects and a 0.88m increase in sea level over the next century would be prudent to consider in the design of these long-life structures.

Industry requires better direction on what measures should be considered when planning and designing road infrastructure. Sea level rise maps such as those published by the Environment Agency in the UK or nominated quantities in design standards would be appropriate and should be considered by relevant authorities.

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