Local Council Infrastructure and Climate Change

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Paper presented at the State of Australian Cities Conference

Melbourne

November 2011

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INTRODUCTION

The International Panel on Climate Change (IPCC) Fourth Assessment Report (FAR) states that the warming of the climate system is now "unequivocal", and is "evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). It is also likely that despite current mitigation policies and related sustainable developments, the level of greenhouse gases in the atmosphere will continue to increase over the next few decades. As a result, the global climate system will very likely see changes that exceed those observed over the past century.

Over the coming decades, southern Australia is likely to experience continued increases in temperature, changes in rainfall (likely reductions in winter and spring), an increase in daily rainfall intensity but longer dry spells between rainfall events, an increase in evapotranspiration (the combined effects of evaporation and plant transpiration), an increase in very hot days and nights, a reduction in the frequency of frosts and snowfall events, a likely increase in the number of extreme fire danger days, sea level rise and increased frequency and height of storm surge events.

LOCAL GOVERNMENT ASSET MANAGEMENT

Within this changing climate, Australia's 560 local government authorities are responsible for the management of assets valued at approximately $212 billion (ALGA ,2010). Many of these assets (buildings, roads, footpaths, coastal retaining walls, water infrastructure, etc.) have a life span greater than 50 years and so will be affected by long-term shifts in climate such as sea level rise as well as changes to the return periods and intensity of the extreme events including heat waves, bushfires, hail and cyclones. How these changes in the climate will impact on existing council assets and their management has not been well understood and existing financial and asset management tools have not effectively incorporated climate change scenarios into municipal planning processes. The research problem addressed in this paper concerns how Australian cities, through the agency of local government, might adapt in a planned and cost effective manner to the impacts of climate change on these infrastructure assets.

The challenge for local governments Australia wide is to adapt to the likely impacts of climate change in a timely and feasible way. To date there has been very little information and no available tools to translate these impacts into municipal financial and asset management plans. Councils have indicated that they are overwhelmed by the amount of information made available to them on climate change but do not know how to translate this information into planning processes to improve their capacity to adapt the built environment to a changing climate. The research undertaken in the larger project of which this paper represents a part, delivers a set of guidelines and technical modelling tools designed to fill this gap and provide a clear, comparative financial analysis of adaptation options for the management of local government assets.

Historically, maintenance and replacement of hard infrastructure in council has been guided by the principles, models and tools provided in the International Infrastructure Management Manual, developed by the Institute of Public Works and Engineering Australia (IPWEA) in conjunction with councils, engineers and manufacturers of various components and materials. However, due to the limited information on potential impacts on infrastructure due to climate change, these tools have not allowed for the incorporation of climate change impacts and the likely flow-on effects to asset and financial management.

METHODOLOGY

The current paper comments and reports on the initial stages of a larger project concerned with identifying the key council assets which may be vulnerable to climate change and assessing the likely effects on these infrastructure assets of different climate conditions and events. Specific research questions addressed here include what are current approaches taken by local government to deal with infrastructure management; what level of information exists in respect of deterioration through climatic as opposed to use factors; what types of infrastructure assets and materials may be vulnerable to climatic changes; and what new approaches could be developed to assist in managing infrastructure in a changing climate?

The IPWEA methodology which employs a suite of software and other elements known as NAMS+, represents the industry standard for the generation of local council asset management plans. This technique classifies infrastructure by type, eg roads, buildings, storm water systems, jetties etc. It then breaks these different sorts of infrastructure into components. For example a typical road would be analysed in terms of its component elements, namely sub base, base course, sub grade, pavement, kerbs and drainage. These different components are made up of a variety of materials such as rubble, concrete, bitumen etc. By a combination of matching data from existing records on specific assets with field survey of asset condition, asset managers record a value measured in years, which quantifies the remaining life of specific assets. This assessment takes into account deterioration of the asset from natural elements as well as from use. The critical variable in the process of factoring climate change into the NAMS+ system is the calculation of remaining asset life which flows from the above considerations. Changing climate may shorten or in some cases lengthen, remaining life of assets with consequent implications for local council finances and cash flow as increased maintenance or early asset replacement may be required. To begin a comprehensive review of the technical literature on materials durability was undertaken. From a long list of typical council assets, the predominant materials were identified as concrete, steel, bitumen and timber. Literature mainly situated in the fields of materials science and engineering yielded significant data on the vulnerability of these materials to changes in ambient conditions such as heat, wetness, abrasion, wind gust, chemical changes in air or water and drying. Thus the analysis sought to determine whether it is possible to quantify with any degree of accuracy deterioration of materials and hence asset life expectancy. The literature also yielded evidence of modelling related to deterioration through climate factors and usage which had potential to be adapted to reflect changing climate conditions. Later steps in the project will use outcomes of the literature review to create a probabilistic model based on climate change data to allow calculation of the remaining life for a range of assets. Early in the project it was decided to concentrate on human constructed infrastructure only, so green infrastructure such as parks, gardens and trees was intentionally excluded from consideration. These ecosystem service elements are seen as crucial aspects of urban life but were considered too complex for the methodology in the current study.

CLIMATE CHANGE THREATS TO INFRASTRUCTURE

The literature on the potential or actual experience of climate change to impact on infrastructure assets is relatively sparse. A report on the impacts of the 2009 heatwave across Southern Australia includes consideration of a range of major infrastructure assets including railways and electric power generation and transmission. Whilst most of the assets discussed in this report are unlikely to be owned by local councils, it is clear from the actual experience of several days of extreme temperatures that transport and electricity distribution networks were placed under significant stress to the extent that network shutdown resulted. 25% of the Melbourne metropolitan rail services was cancelled as a result of buckled rails and heat related issues and rolling electricity blackouts resulted from unprecedented peak demand for electricity allied to supply problems caused by system trips as result of overheating (Reeves et al, 2010). Catastrophic failure of infrastructure from natural disasters is well reported as in the case of Los Angeles following the 1994 Northridge earthquake which destroyed roads and bridges as well as seriously damaging 25,000 dwellings (Olshansky, Laurie & Topping, 2007). New Orleans, following Hurricane Katrina is also extensively reported though mainly from a social perspective. Taylor and Philp (2010) provide a useful overview of the likely risks and important considerations for future design of infrastructure in respect of climate change. They report on a range of transport related infrastructure items and note the rapidly rising insurance costs of such infrastructure over the last decade. There is a growing literature which discusses the overlap between disaster risk reduction and climate change (Solecki, Leichencko & O'Brien, 2011 forthcoming) and especially in respect of governance, economic losses (Schmidt, Kemfert & Hoppe, 2009) and policy responses aimed at developing resilience. The majority of the available literature appears to focus on hazard reduction in respect of single events that have the potential to destroy or make unavailable particular infrastructure assets but there is much less discussion of the cumulative and relatively slow progressive impact of climate change on infrastructure. In the following paragraphs therefore we examine the literature on concrete, steel, bitumen and timber as key constituents of many types of council owned infrastructure, with a view to identifying whether this literature can assist in quantifying deteriortaion rates and identifying risks resulting from climate change .

Concrete

The literature suggests that concrete deterioration can be classified into two primary classes: physical and chemical. Both these classes of deterioration act simultaneously on the material and their effect is superimposed such that concrete that is subject of physical deterioration becomes more vulnerable to chemical deterioration and vice-verse (Mehta and Monteiro, 2006). Concrete physical deterioration can manifest as surface wear or cracking. Physical processes that cause concrete to crack are classified in the literature as being in three groups: 1) significant volume change due to temperature and humidity gradient; 2) severe structural loading, and; 3) exposure to extreme temperatures in freezing or fire (Mehta and Monteiro 2006).

It is known that under normal/nominal temperature and humidity conditions, the volume of concrete in a given section changes as conditions fluctuate; however, with current Australian climate and climate change predictions suggesting that more extreme heat-wave and high-humidity events become common, there is concern relating to whether or not concrete can withstand sustained extreme climatic conditions. Nonetheless, both temperature fluctuations and extremes are considered within the Australian Standard (AS) where properly designed concrete structures would include contraction and expansion joints to minimise the impact of any aberrant temperature/humidity events and thus minimise potential cracking (Woodson, 2009). Severe structural loading may be impacted by extreme storm conditions which could result in failure, but again Australian Standards demand that concrete structures are built sufficient to deal with currently predicted extreme wind loadings. In respect of temperature extremes the probability of extreme cold/freezing events is relevant in Alpine areas in Australia though climate change models suggest that temperatures are more likely to rise than fall, so the potential damage associated with the freeze-thaw cycle is not a major consideration. On the other hand, higher temperatures and dryer conditions may lead to more bushfire events which could lead to asset damage. These represent single catastrophic events which will probably require damaged sections of structural concrete to be rebuilt or have the appropriate segments replaced.

In normal non-acidic environments there is no threat from chemical deterioration for concrete structures in good condition with low permeability (Mehta and Monteiro 2006). However, concrete structures can be surrounded by environments that contain active chemical agents. In such circumstances concrete durability is weakened by chemical reactions that occur within the concrete. Also, in the case where climate change will lead to a significant increase in rainfall, it is expected that increased deterioration of concrete can occur due to soft water contact. Standards consider the effect of soft water and stipulate an appropriate mix of concrete is used to ensure that any soft water contact causes minimal decomposition(Council of Standards Australia, 2009).

Concrete is susceptible to oxalic acids which are present in decaying animal waste or vegetable matter. (Mehta and Monteiro 2006). In flooding events where sewage overflow may occur, this type of deterioration may take place in concrete which has not designed to withstand this form of chemical attack. Climate change may increase the frequency of floods in some areas and therefore, attention should be paid the potential of non-oxalic treated concrete structures deteriorating more rapidly in this situation.

Where concrete structures have not been designed to cope with direct seawater contact they may suffer increased levels of deterioration as a result of replacement of Ca^{2+} ions with Mg^{2+} ions(Mehta and Monteiro 2006). In marine environments, concrete, which does not comply with the Australian Standard, deteriorates in short period of time due to sulphate attack, steel reinforcement corrosion, abrasion and cracking from frequent wetting and drying. (Ahmad 2006) In the event of storm surge concrete may be submerged by sea water. When water retreats chemical agents remain in concrete pores opening the possibility of sulphate and chloride attack. Finally carbonisation-induced concrete corrosion is a major area of investigation in ongoing CSIRO research. The studies conclude that there are design and/or maintenance aspects to be specifically considered across all stages of the life cycle of concrete structures. Current standards may be insufficient to deal with carbonation induced corrosion as atmospheric CO_2 concentrations increase in future. Thus, existing structures may become more prone to failure and new structures will require construction to amended standards of cover design, selection of cement and mix, selection of concrete strength, coating design and cathodic protection (CSIRO, 2010).

Our review of concrete durability found that concrete is relatively resilient to climate change. In fact, concrete could increase its applicability in construction, because of its excellent durability. For example, concrete pavement could replace bitumen paths because concrete will perform better in relation to increased temperature scenarios. Concrete durability can be improved through the use of technologies such as admixtures which can alter the characteristics of the concrete before mixing and with variations in cement/water ratios used during pouring (McCarthy and Giannakou, 2002; Memon, Radin et al., 2002; Mehta and Monteiro, 2006; TheContructor.org 2010); Importantly, concrete may be resistant to deterioration in certain environments and not in others, as such, the final composition of the cement and pouring water ratio is determined by the environment in which the cement structure will be constructed (Mehta and Monteiro 2006). Australian Standard AS3600-2009 takes into account the manner in which concrete deteriorates and defines the appropriate composition of concrete that should be used (Council of Standards Australia, 2009)

The major threat to concrete in infrastructure components is where frequent exposure to sewage results from storm surcharge. This is likely to occur where urban storm water and sewerage systems are separate but during extreme rainfall periods sewage may infiltrate the storm water system. Sydney is an example of a city where the system is currently unable to cope with extreme rainfall, causing sewer surcharge.

Steel

In respect of steel Cole (2010) suggests the interaction of two main parameters determines the metal corrosion rate. These factors are time of wetness and acidic level of moisture on the metal surface. In respect of wetness the longer the metal is exposed to corrosive chemical reaction, the more prone it is to corrosion. Climate change is likely to impact on these prime factors for metal corrosion. Time of wetness depends on a complex interaction between temperature, rainfall and humidity. The acidic level of moisture on metal surfaces is primarily dependant on levels of air pollution. However, meteorological parameters, such as temperature and rainfall also influence acidic level. For example, higher temperatures would stimulate more gaseous absorption in water. Several studies have attempted to model the corrosion rate of steel and zinc coating in respect of atmospheric conditions. (Rodríguez, Hernández et al., 2003) (Feliu, Morcillo et al. 1993a); (Feliu, Morcillo et al. 1993b); (Svensson and Johansson 1996) (Hayniex, 1987)

Several conclusions may be drawn from the literature. Firstly, it is very challenging to isolate the effect of meteorological parameters on metal corrosion. In all models meteorological parameters are involved in non-linear mathematical operations with air pollution parameters. As a result of this, the same change in meteorological parameter can cause dramatically different impacts on the corrosion rate if different air pollution circumstances are considered. It can be concluded that any developed general model for the influence of meteorological parameters will be limited in its ability to express the significant influence of local factors on corrosion rates.
Local factors determine the importance of the parameters considered in the model. Sometimes their importance is so substantial, that they completely change the manner in which parameters influence the corrosion rate. The detailed review of models reveals that the unique combination of circumstances in each case is vital for prediction of the future corrosion rate.

Every typical environment listed in AS 4312-2008 is defined in terms of meteorological and air pollution parameters. The predicted corrosive rating is determined by the typical air pollution for the environment and the typical time of wetness, which depends on the typical meteorological parameters for that specific environment. The longer the metal is wet, the longer it is subject to corrosive attack. Based on that assumption, a simple model of five environmental zones has been developed. This is illustrated in Table 1 below. Thus climate change which causes a significant shift in ambient humidity may shift a location from one zone to another, accelerating corrosion rates in steel, necessitating earlier replacement.

Table 1 : Environmental zones for atmospheric metal corrosion according to AS 4312-2008 (Standards Association of Australia 2008)

ISO 9223 category	Corrosivity rating	Steel corrosion rate – Microns/year	Typical environment
C1	Very low	<1.3	Dry indoors
C2	Low	1.3 - 25	Arid/urban inland
C3	Medium	25 - 50	Coastal/industrial
C4	High	50 - 80	Marine (calm water)

C5	Very high	80 - 200	Marine (Ocean surf)

The most common approach to protect steel components is to apply protective surface coatings such as galvanising with zinc. The same principles for model developments are valid for zinc corrosion and therefore similar models could be developed for zinc corrosion.

Bitumen

The most commonly used surface sealant for roads in Australian is bitumen. Its design life is dependent on the rate at which it hardens and becomes brittle, which then causes traffic wear to accelerate and the road surface to crack and deteriorate. So bitumen with better durability is more resilient to hardening. In Australia, an ARRB durability laboratory test is used to determine the durability of bitumen types (Standards Australia 1997). The test exposes the sample of bitumen to prolonged extreme heat and observes the time in days for bitumen to reach a specific viscosity measure. Research is constantly refining the advice for road constructors in an attempt to improve durability and road life. Durability levels for various type of bitumen used in Australian can be found in “Durability of Australian Bitumens 1956-2004” report (Austroads 2007). Various models have been developed to predict the hardening rate. Since all these models include air temperature parameters it should be possible to use the models to predict the impact of increased temperatures on road seal durability.

An increase in daily temperatures impacts on the rate of bitumen hardening, and on the bitumen distress viscosity. Bitumen hardens faster in warmer/hotter climates, and bitumen distress viscosity is higher in a warmer/hotter climate. However, the effect of the increased hardening rate on seal service life is more significant than the effect of the higher distress viscosity on service life. Thus seal service life is shorter at warmer climates. Also increased rainfall will increase stone loss from asphalt mixes. Most of the modelling work so far conducted relates to major highways and so there is some question as to its relevance to local council owned roads which may be constructed to different standards and carry significantly less traffic. Nevertheless work by Martin (2010), which employs the Thornthwaite Moisture Index approach, has potential for providing a predictive model which can use climate data input to predict bitumen deterioration rates on different sealed road types and thus allow revisions to remaining asset life calculations.

Timber

Weathering is the effect of natural forces on timber. That includes sunlight, wind, rain and temperature. Unprotected timber suffers deterioration from weathering. (National Association of Forest Industry – NAFI, 2003) For example, heat reduces moisture in the timber and causes shrinkage leading to splitting and cracking (Lyons, 2006). Moisture causes timber to swell. When it dries out timber shrinks and its grain opens for further deeper moisture penetration. The results are slow disintegration of unprotected timber surfaces and the decay of wet inner parts. (Son and Yuen, 1993) Protective coatings minimise the effect of weathering. Sufficient technologies are available to prevent timber deterioration at various weather conditions, regular maintenance being the key for successful protection from weathering. (Morrell, 2005). So a change in the climate requires change in the maintenance routine. Insect and fungal attack is a further hazard with timber. The most common insects to attack timber are termites, lyctine beetles, and anobiid bores. Changes in temperature could provoke changes in fungi population. (National Association of Forest Industry - NAFI 2003; Morrell 2005). Effective protection exists against insect attack. Usually timber is protected by initial and regular chemical treatments. In the research literature, there are suggestions that climate change may change the distribution of insect populations (URS Forestry, 2008). If climate change leads to increase of insects or fungi causing timber damage, then timber maintenance regimes may need to be changed.

Timber that is submerged in seawater is exposed to hazardous attack by active marine organisms. Some of the greatest threats are bivalve molluscs, and crustaceans. Appropriate treatment with chemicals and timber selection could provide sufficient protection against marine organisms. (National Association of Forest Industry - NAFI 2003) Again monitoring of the habitat of marine organisms causing timber degradation is required to ensure effective timber protection against climate change.

DISCUSSION

The above review of materials deterioration in respect of climatic factors suggests the following.

The choice of materials in assets is highly dependent on environmental conditions. Australian standards (e.g. AS1684.1, AS 1684.2, AS 3600) specify in what conditions and circumstances particular materials and construction technologies should be utilised for construction. These standards are designed to guarantee serviceability of the asset, by making them durable to environmental influence and resilient to expected extreme events. Furthermore extreme circumstances are factored into the Australian Standards such that in most circumstances the materials design should be capable of dealing with a changed climate. However, future infrastructure will need to be built to different standards to take into account the constantly moving frontier of extreme climatic events. So Australian Standards will need to be revised periodically to ensure infrastructure is constructed to withstand ever more extreme conditions. Parallel revisions to mapping of climate zones is also likely to be needed to assist in the assessment of corrosion for steel or the degradation of timber as result of changes to humidity or temperature.

It is also important to note that assets that are constructed to be resilient to specific environmental conditions may become vulnerable to other environmental factors, which have not been predicted to be present during their design life. Examples could include concrete structures designed for terrestrial environments which become periodically or permanently exposed to salt water. Also more frequent flooding events which cause sewage flows to be diverted into concrete systems not designed to cope with them are a particular concern. Structures which have not been built according to Australian Standards are particularly vulnerable. Footpaths constructed from concrete or bitumen which has not been adequately specified are a case in point. As well as having to cope with increased maintenance costs councils may be faced with law suits from persons injured from tripping on surfaces that have suffered surface heave. Increased maintenance may also be necessary on older wooden structures such as timber jetties and bridges as previously non native types of insect and fungus threaten their integrity. Table 2 summarises the main climatic concerns which are identified in the literature review.

Table 2: Summary of climate impacts on materials and infrastructure

Material	**Infrastructure asset**	**Climate factor**	**Risk**
Concrete	Storm water pipes	Increased temperature/ drying soils	Cracking
	Storm water pipes	Intense rain/ floods/ sewer surcharge	Chemical changes / weakening
	Footpaths	Increased temperature/ drying soils	Cracking
	structures	Intense rain/ floods Soil saturation	Chemical changes
Gravel	Roads (sealed)	Increased temperature/ drying soils	subsidence
	Roads (unsealed)	Intense rain/ floods	Surface scouring
Steel	Structures	In creased humidity	Accelerated corrosion
Bitumen	Roads	Increased temperature/ humidity	Increase wear
	Footpaths		
Timber	Jetties	Sea temperature rise	Fungal and marine organism attack
	Bridges	Seal level rise/ salinisation	Chemical changes
	Structures	Increased temperature/ humidity	Drying/ splitting/ insect attack

Therefore, there is a probability of significant climatic impact on assets in regions where climate change will lead to a dramatic switch of environmental conditions e.g. from a dry to a wet climate or the incidence of heatwaves in regions which previously did not experience them. Increased humidity is a particular aspect which should trigger concern by local councils in respect of corrosion of steel in structures and road surface wear. Significant rainfall increase causing stormwater flows through concrete pipes and culverts may also increase deterioration as result of chemical action the concrete. This new reality could significantly deteriorate asset condition, shorten its service/design life, affect the level of service, and require alterations in its maintenance. Whilst the evidence on materials deterioration is detailed there are only a few instances where it is capable of quantification. It may be possible to model and predict corrosion of steel and associated protective coatings and similarly to quantify the acceleration of wear to bitumen road surfaces to enhance the value of asset management plans to local councils by explicitly identifying climate impacts on costing planned maintenance. But even with these materials the range of variables which can affect deterioration is extensive and complex. Finally, the issues of loss of service and complete failure of infrastructure are not addressed by the approach outlined above. A road or bridge which is rendered unusable as a result of flooding for example, may or may not require repairs but as the return period of floods increases and the infrastructure asset experiences longer and more frequent periods of loss of service, decisions about replacement in alternative locations will need to be taken. These will imply significant costs, which will require programming in order to smooth out local council infrastructure spending. Destruction or severe damage to council infrastructure will also increase as return periods of floods, cyclones, bush fires and storm surges reduce. Asset management plans will need to take climatic data into account. The key driver for the revision of these plans is likely to be budgetary, with local councils adapting their approach to maintenance, design and asset replacement and setting their priorities on the basis of the finance available to address vulnerable assets. In many parts of Australia unsealed roads are a concern, since they are particularly vulnerable to extreme rainfall and flooding. A second stage of the research has attempted to examine infrastructure from an holistic as well as a materials perspective and this has included investigation of models that attempt to simulate deterioration in road infrastructure using wear from use and climatic conditions as the main dynamics. It is too early to provide any definitive conclusions but the existence of such models does suggest that they may prove valuable tools in developing an approach to assessing incremental impacts of climate on local council infrastructure.

CONCLUSION

The above discussion has taken a materials based analysis approach to attempt to predict and quantify potential deterioration in a range of local council owned assets, such as roads, stormwater systems, bridges, jetties and other assorted structures. We conclude that there is a considerable literature available, which documents factors which contribute to materials degradation and climatic factors such as temperature and humidity are amongst these. Often the complexity of effects causing deterioration is such that it is difficult to isolate climatic factors from others such as differing design, materials quality and changing usage rates. In respect of roads, the work of the ARRB does allow a model to be constructed that takes changing temperature and moisture into account to predict the likely change to road seal life. This is capable of being integrated into the NAMS+ system and may provide useful information for local government asset planners. Given that roads are, by value, typically the largest asset which local councils have to manage and maintain, this is a valuable finding. It may be problematic to quantify changing life expectancy of other infrastructure such as footpaths and jetties about which much less specific data may be recorded and where no technical modelling work is available. Nevertheless, the above analysis is useful in terms of risk assessment in that it identifies a number of potentially higher risk situations such as immersion of concrete not designed for marine environment or the potential for insect and fungal populations to infest timber structures which are not suitably proofed to deal with such pests, pointing to a need for vigilance and alterations to council asset management practices in certain cases. Thus the planning and management approach taken by local councils to the maintenance of their infrastructure assets will need to change in future. A more strategic assessment requiring risk assessment and cost benefit analysis of recurrent maintenance is suggested. In future this will need to be supported by amendments to Australian standards to take into account changing climate zones and conditions. Such a changed approach, allied to the modelling of specific assets where possible, should assist Australian local councils better respond to changing climate conditions over the next decades. The current research project will trial variations to the NAMS+ system in 2012, aiming to produce practical output later in the year.

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