Transport & ICT

Integrating Climate Change into Road Asset Management

WORLD BANK GROUP

Technical Report
APRIL 2017

1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

Acknowledgements

This report was prepared by Theuns Henning, Susan Tighe and Ian Greenwood under the overall direction of Christopher R. Bennett, with contributions and inputs from the following Transport and ICT staff: Shomik Mehndiratta, Fiona Collin, Simon Ellis, Vincent Vesin, Arnab Bandyopadhyay, Svetlana Vukanovic, Sara Sultan, and Christine Howard.

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Overview

Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision-making based upon quality information and well defined objectives. This definition from AASHTO[1] envisages an end-to-end process, which is able to address both the short-term and long-term needs of the assets, in order to deliver the services to those using the road, in the most cost-effective manner.

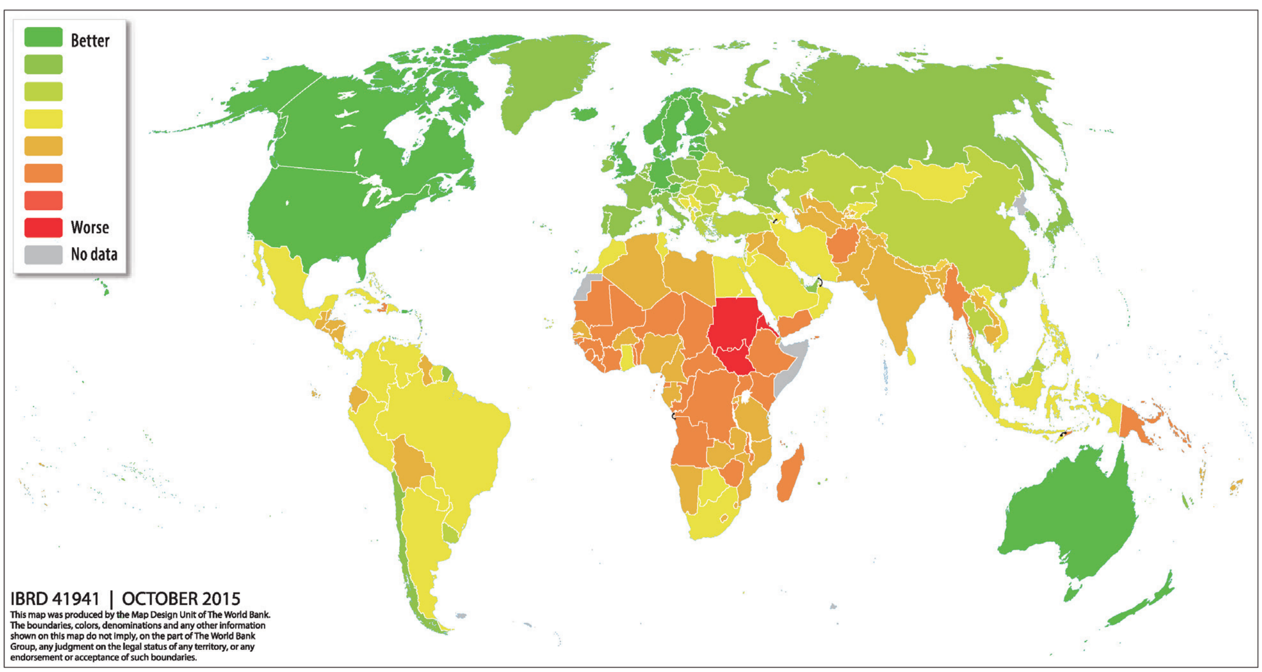
Climate change, in the realm of asset management is being considered as a disruptive force within the otherwise stable asset management process. While there are many theories on what is causing climate change (and equally how to prevent it from worsening), evidence suggests that the climate is changing with two key outcomes being observed:

- Average temperatures, rainfall and other climate related indicators are changing from year-to-year; and
- Extreme events are occurring more frequently than in past decades.

The impacts of climate change are not expected to be equally shared by all countries, illustrating that many of the less developed countries are also facing the greatest vulnerability to climate change impacts. The impact, however, will not be isolated to countries with higher vulnerability, it will affect everyone.

The question then arises as to how road authorities should go about integrating climate change thinking into their business-as-usual asset management processes.

Figure O.1: Vulnerability of Climate Risk on Global Level (Ebinger and Vandycke, 2015)

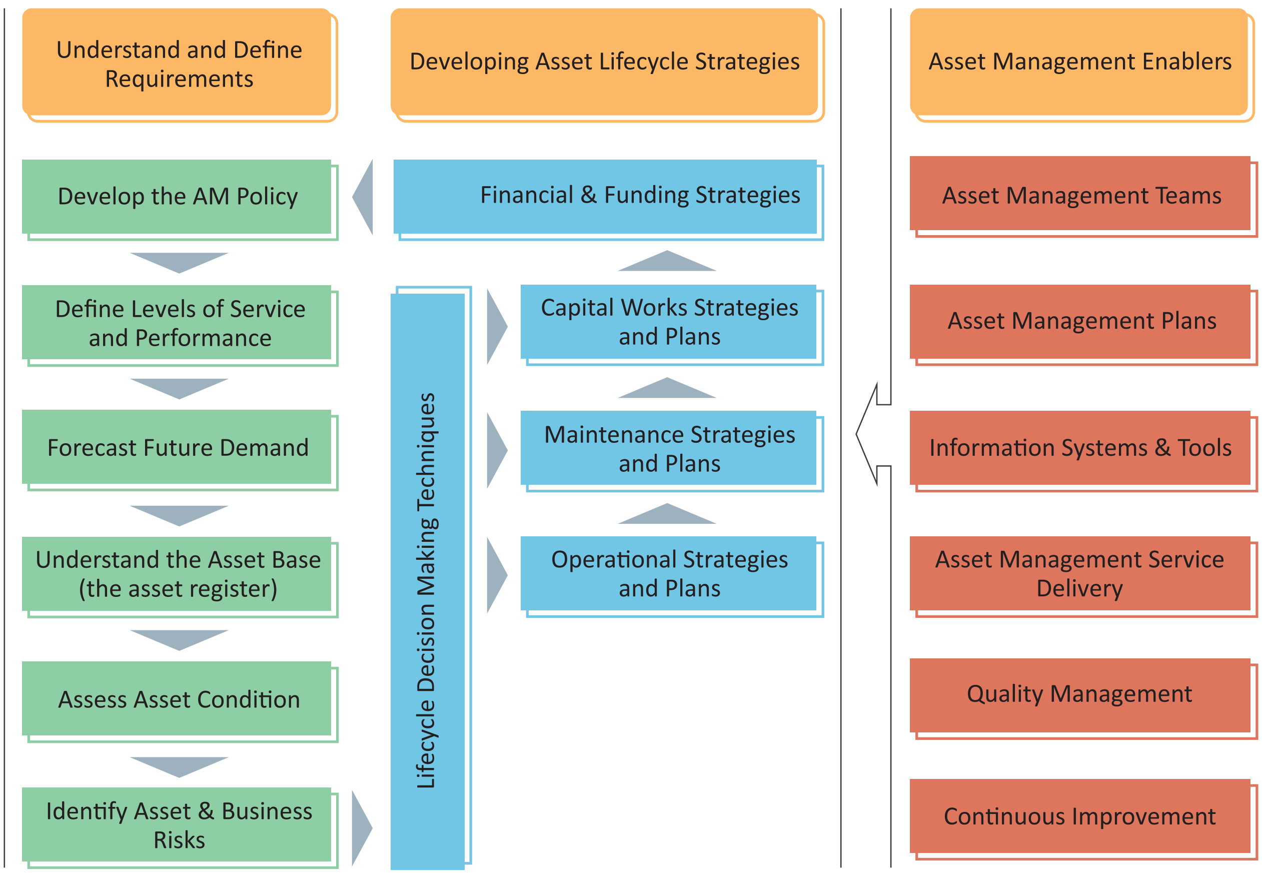


1 America Association of State Highway and Transport Officials, Subcommittee on Asset Management, Strategic Plan 2011–2015

The Asset Management Process

There is no universal asset management process that all road authorities follow. Here, the AM Process from the International Infrastructure Management Manual (NAMS, 2011) has been adopted as per Figure O.2. It is envisaged that those road authorities following a different process, will be able to identify largely similar steps in their processes and from this, still be able to relate to, and implement the recommendations.

Figure O.2: Asset Management Process (NAMS. 2011)



Climate Change – Slow Changing versus Shock Events

Road networks are the socio-economic backbone of any community. They provide access and movement of people and goods that fulfil all the functions necessary for people in a community to live and prosper. Roads mostly consist of natural gravels in combination with other materials such as asphalt and concrete. The design of the pavements and materials takes into account the natural impact of the environment. Engineers are well aware of the negative impact water ingress has on pavements and design the pavements and associated drainage assets to counter this impact. Likewise, asphalt and other surfacing materials are designed for prevailing climatic conditions including rainfall and ambient temperatures expected during the design life of the surface.

Both rainfall and temperatures are starting to vary beyond the accepted design envelopes in the current design methods and standards of road pavement, surfacing and drainage structures. While slow changing environmental impacts put strain on the performance of the road network, a more significant impact is often observed from shock events of weather patterns.

Historical design methods expect shock events to exceed the design parameters on the premise that these events are infrequent. Recent studies have strongly indicated these shock events to be increasing in frequency and intensity, such that roads are now subject to more extreme events within their design life. Simply accepting these events to exceed the design capacity of roads and structures is not a sustainable option any longer as there is a shortening of life cycles and/or temporary loss of accessibility. As an example, Table O.3 lists the main climate change events expected in the Nordic countries and how these impact on the road infrastructure. The NDF (2016) report also lists a number of mitigation or adaptation techniques to combat some of the impacts listed in the following table O.3.

In general, the long-term changes in average climatic indicators can be readily assimilated into the AM processes owing to the life cycle of many road assets being less than that of the time it takes for significant change to occur. The main exceptions being around very long life assets such as structures and major drainage assets wherein designing for the climate that is present today will likely not meet the requirements throughout the life of the asset.

Shock events occur frequently even within the lifecycle of the shorter-lived road assets and therefore needs to be considered as part of the day-to-day business of the road authority. This includes preparing in advance of the events; how to respond during an event; and what is to be rebuilt after the event to ensure a ‘build back better’ outcome is achieved to make the network more resilient for when the next event occurs.

Table O.3: How the Climate Could Impact on Roads (NDF, 2016)

Climate Change Events	Risks to the Road Infrastructure
Extreme rainfall events	• Overtopping and wash away • Increase of seepage and infiltration into pavement and subgrade • Increase of hydrodynamic pressure of roads • Decreased cohesion of soil compaction • Traffic hindrance and safety
Seasonal and annual average rainfall	• Impact on soil moisture levels, affecting the structural integrity of roads, bridges and tunnels • Adverse impact of standing water on the road base • Risk of floods from runoff, landslides, slope failures and damage to roads if changes occur in the precipitation pattern
Higher maximum temperature and higher number of consecutive hot days (heat waves)	• Concerns regarding pavement integrity, e.g. softening of asphalt layers, traffic-related rutting, embrittlement (cracking), migration of liquid asphalt • Thawing of permafrost solid resulting in subsiding structures and roads • Thermal expansion in bridge expansion joints and paved surfaces • Impact on landscaping • Temperature break soil cohesion and increase dust volume which cause adverse health impacts and traffic accidents
Drought (Consecutive dry days)	• Susceptibility to wildfires that threaten the transportation infrastructure directly • Susceptibility to mudslides in areas deforested by wildfires • Consolidation of the substructure with (unequal) settlement as a consequence • More smog • Unavailability of water for compaction work • Drought decreases mortality of plants along road alignments
Extreme wind speed	• Threat to stability of bridges • Impact of wind borne debris on network/safety • Damage to signs, lighting fixtures and supports • Increase of wind speed causes the dynamic force of water generated by waves on road embankments
Foggy days	• Traffic hindrance and safety • More smog

Response to Climate Change

Prior to Events

As part of the business-as-usual practices within a road authority, there are a number of actions that can be taken to prepare for climate change (both long-term changes and shock events) with these including:

- Identifying key (life line) routes recognizing the many roads are also corridors other essential infrastructure such as water, power etc.;
- Having agreements in place on how the damage from major events will be funded and who will be entitled to financial support;
- Developing models that predict the impacts of climate change events on the road network, including the collection of data to feed and calibrate these models;
- Defining what resilience means for different road categories and making residents and road users aware of how long they may be without transport access after events;
- Having contracts in place with the private sector to respond to shock events when they do occur;
- Revising design guides to take into account the changing frequency of climatic events;
- Retrofitting infrastructure that is found to be deficient; and
- Trialing new materials that may better resist climate change.

During and Immediately After Events

During major shock events, most road authorities will be focused on the monitoring of the network and making road closures as necessary to ensure that safety is not compromised. In the immediate aftermath, roads will typically be reinstated to facilitate basic access. It is during these periods that much of the prior planning will come into benefit.

Post Events

After the initial response is over, if large scale damage has occurred, there is an opportunity to build back a road network that is more resilient to future events for relatively little (if any) additional cost. Furthermore, there will be an opportunity to use data collected during the event to update predictive models and to refine processes further.

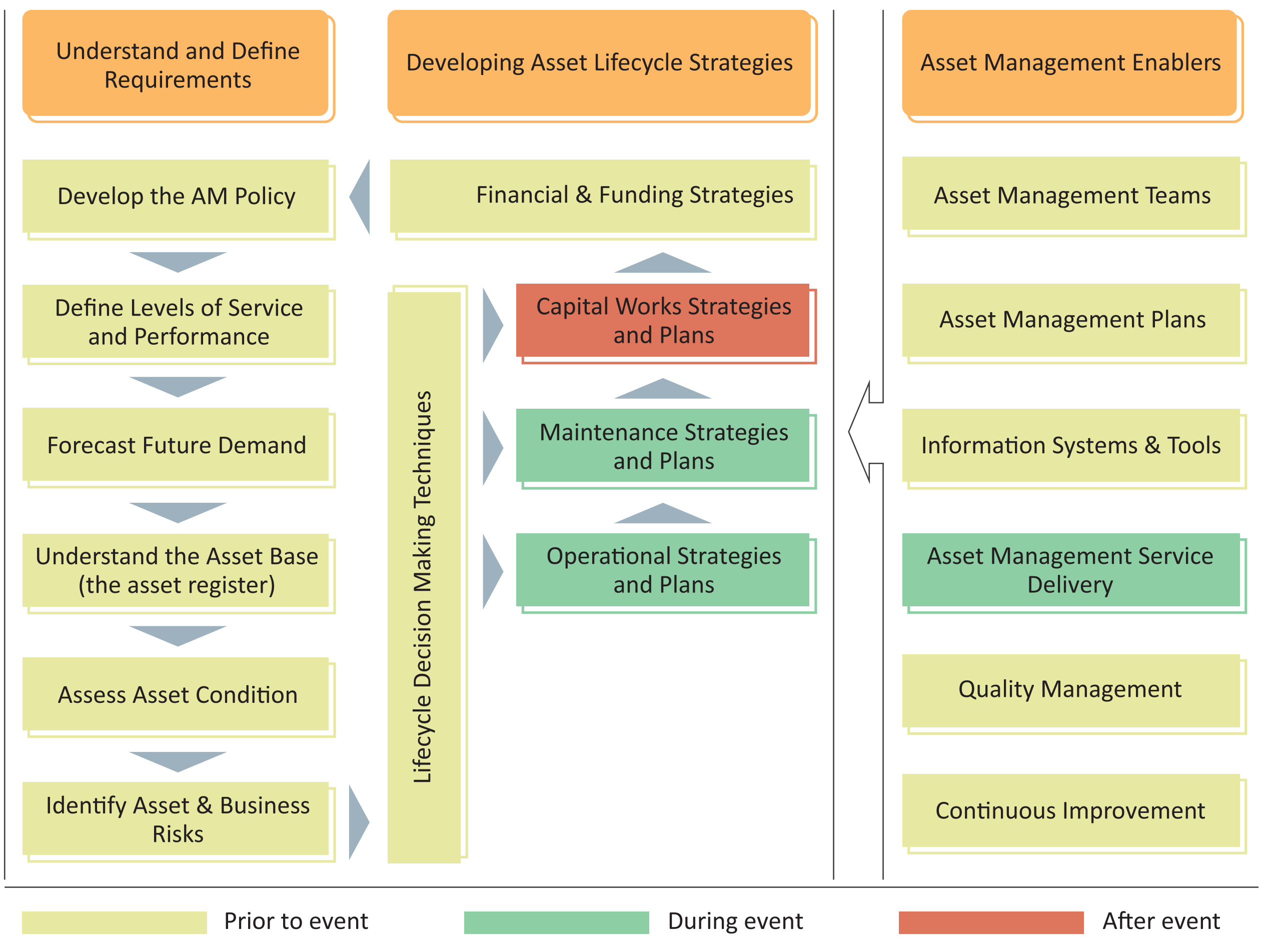
Disaster Response and the AM Process

Figure O.4 takes the previously presented AM process and overlays the above discussion on responses. Of note is that most of the means of integrating climate change into asset management is related to being prepared in advance of the event. Only three activities arise during the event, and one after.

During the event, the response is largely restricted to the operational and maintenance plans in place, and the format of any service delivery contracts. In the long term, the response is largely constrained to the capital works strategies that are in place.

Collectively this all points to a position that the best time to address climate change is before you need to deal with it – i.e. now.

Figure O.4: AM Process versus Response Timing



Recommended Approach to Integration of Climate Change into Asset Management

Table O.5 contains a recommended series of actions for road authorities to undertake across the full scope of asset management. Not all recommended actions will be applicable to all road authorities, although it is certainly advisable to at least consider each within the overall asset management improvement process.

For some highly vulnerable road networks, actions beyond those in the table may be necessary. In extreme cases these steps may go as far as abandonment of certain road assets that cannot be reasonably protected from climate change. While such a decision is feasible from an asset management decision making process, the consequence of such a decision is beyond the scope addressed in this study – which is predicated on the basis that existing routes would be developed and protected from climate change.

Table O.5: Recommended Actions to Integrate Climate Change in AM Practices

Phase	Step	Key Additional Actions
Understand and Define Requirements	Develop the AM Policy	• Specifically address climate change within the AM Policy statement, including what horizon is to be planned for • Have agreements in place on how the damage from major events will be funded and who will be entitled to financial support
	Define levels of service and performance	• Ensure network resilience measures (e.g. restore all major roads within 12 hours of end of 1:100year flood) are included into the level of service framework • Revise design guides to take into account the changing frequency of climatic events
	Forecast future demand	• Future demand forecast such as demographical changes and traffic loading increases should be integrated with climate change impacts on the expected performance of infrastructure • Providing for future growth in areas of high vulnerability should be avoided
	Understand the asset base	• Ensure that data on drainage assets and their vulnerabilities/deficiencies is complete and up-to-date • All data collection processes should be geospatially referenced • Road data and information should highlight interdependencies with other infrastructure • Link life-lines and critical interactions between asset groups in the base data
	Assess asset condition	• Data collection should include measuring and recording of specific climatic effects on road network • Data collection techniques should also include the focus on quantifying the vulnerabilities of pavements to temperature and moisture changes
	Identify asset and business risks	• Ensure climate change is recognised as a risk to the asset and delivery of services • Risk and vulnerability assessments are already commonly used for climate adaptation. These processes should be integrated with risk management from an organisational risk perspective • The integration with asset management risk in particular promises significant efficiency gains

Phase	Step	Key Additional Actions
Developing asset lifecycle strategies	Lifecycle decision making techniques	• Road asset management and systems brings a wealth of analytics to the climate adaptation topic area • Current analyses processes need to incorporate multi objective capabilities • More emphasis on community involvement in decision making is required when bringing climate adaption into the asset management decision making
	Operational strategies and plans	• Operational plans should include specific allowance for identifying and addressing deficient adaptation measures – such as making sure drainage structure are cleaned and without blockages • Include retrofitting infrastructure that is found to be significantly deficient • Trial new materials that may better resist climate change • Operational procedures should include policies and processes identified for responding to disasters
	Maintenance strategies and plans	• Maintenance strategies and plans should include specific allowance and focus on addressing items that limit the impact from climate change
	Capital works strategies and plans	• Updating of current design criteria (such as drainage design) is needed to allow for changing rainfall patterns • New designs should include specific consideration for climate adaptation technologies
	Financial and funding strategies	• Financial and funding strategies should investigate the impacts of different investment scenarios into climate adaptation • Financial and funding strategies should be in place for responding to potential disaster events

Phase	Step	Key Additional Actions
Asset management enablers	Asset management team	• Effective integration of climate adaptation and asset management must be driven from executive management levels within organisations • Appoint someone as the climate change champion to drive all these actions through the organisation
	Asset management plans	• Ensure that the AMP specifically addresses climate change
	Information management systems and tools	• Information management systems should be including the recoding of specific climatic and impact data for planning purposes • A data residence plan should be in place to respond to disaster planning needs
	Asset management service delivery/ Procurement	• Legislation and procurement processes should allow for the response to shock events
	Quality management	• Quality management of climate adaptation measures need to ensure its sufficient functioning
	Continuous improvement	• Identification of improvements necessary for climate change adaptation

Conclusions

Even though climate change is widely accepted as being upon us, few road authorities have moved beyond cursory consideration of how to include this into their business processes and practices. Unfortunately, many of the most vulnerable parts of the world for climate change impacts are also the least economically developed – meaning that the impacts will be magnified if mitigation measures are not put in place, while at the same time, resources are constrained for investing in effective mitigation measures.

Asset management is an overarching business model that provides the framework upon which climate change initiatives can be readily implemented into a road authority. This transport note and the associated technical report have identified a range of specific actions that road authorities should be considering as part of their asset management practices.

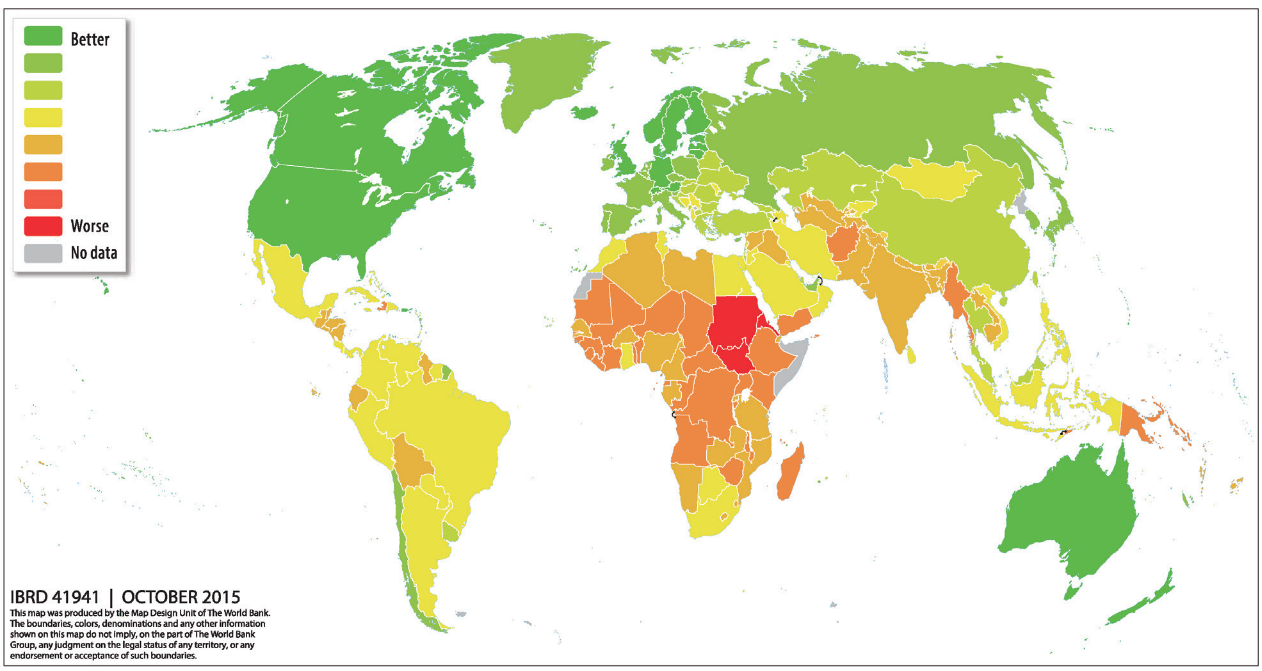
In practice, the vast majority of measures to mitigate climate change needs to be put in place prior to major events to yield maximum benefit and ensure that the services provided by the road network are restored as soon as practicable and that the network is made more resilient after an event.

1. Introduction

1.1 The Changing Climate

There is a wealth of scientific reports that records the actual climatic changes that have been taking place during recent years. While there is debate over the causes of climate change, the rate at which this phenomenon is increasing (World Bank, 2013; and Ebinger and Vandycke, 2015) is overwhelming – with the evidence indicating that the changes in our environment will impact large parts of the globe. Figure 1.1 illustrates the vulnerability for the different regions around the world. It is accepted that some regions will be affected more than others; however, climate change will be a global problem as many of the countries predicted to be most impacted are also the least developed to deal with it.

Figure 1.1: Vulnerability of Climate Risk on Global Level (Ebinger and Vandycke, 2015)

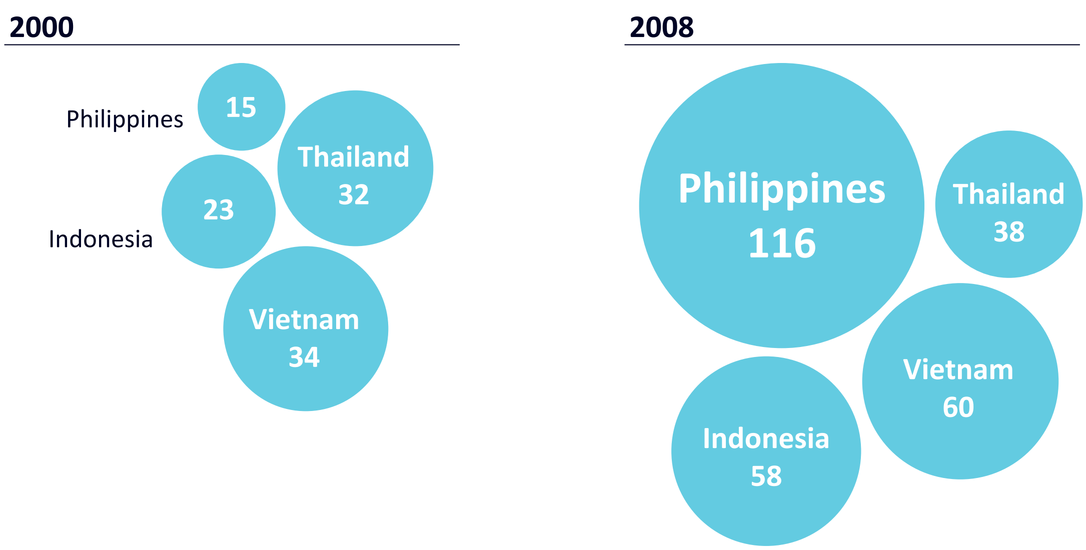


Although the actual climate warming and sea level rise predictions are not massive, the impact on the earth's climatic balance is significant. An observation from literature suggests that climate change results in prevailing weather patterns to be more amplified. Therefore, if extreme rainfall impacted on a country before, the frequency and intensity of these storms are increasing. The same applies to other weather patterns such as droughts. Therefore, one can expect the following impacts on the different regions around the globe:

- Extreme rainfall events;
- Seasonal and annual average rainfall;
- Higher maximum temperature and higher number of consecutive hot days (heat waves);
- Droughts (consecutive dry days); and,
- Extreme wind speed.

Most noticeable is the increase in floods and storms, especially within the South-East Asia region. For example, Figure 1.2 indicates the number of floods and storms for some Asian regions between 2000 and 2008. The significant increasing number of floods is self-evident.

Figure 1.2: Comparing the Number of Floods between 2000 and 2008 (ILO, 2011)



The number of floods is obviously only one part of the statistics, the loss suffered by countries due to these storms are astronomical. For example, Table 1.1 illustrates the damage caused by storms in Samoa since 1990 in terms of the scale of each storm, the damage and losses in GDP. The scale of the damage is significant, being more that twice the annual GDP for some storms.

Table 1.1: Damage Cause by Natural Disasters in Samoa

Event	Return Period years	Asset Damage USD millions 2005 prices	Loss of GDP USD millions 2005 prices	Total GDP USD millions	Loss as % of GDP	Notes
Cyclone Ofa, 1990	25	166	15	161	113	Buildings and infrastructure
Cyclone Val, 1991	100	388	36	163	260	30% agricultural assets
Cyclone Heta, 2004	10	1	4	236	2	Limited damage
Tsunami 2009	50	54	50	277	38	Buildings and infrastructure & tourism
Cyclone Evan, 2012	100	103	100.6	632	29	Productive sector

Source World Bank 2010, and Government of Samoa 2013 (Samoa Post-Disaster Needs Assessment Cyclone Evan 2012)

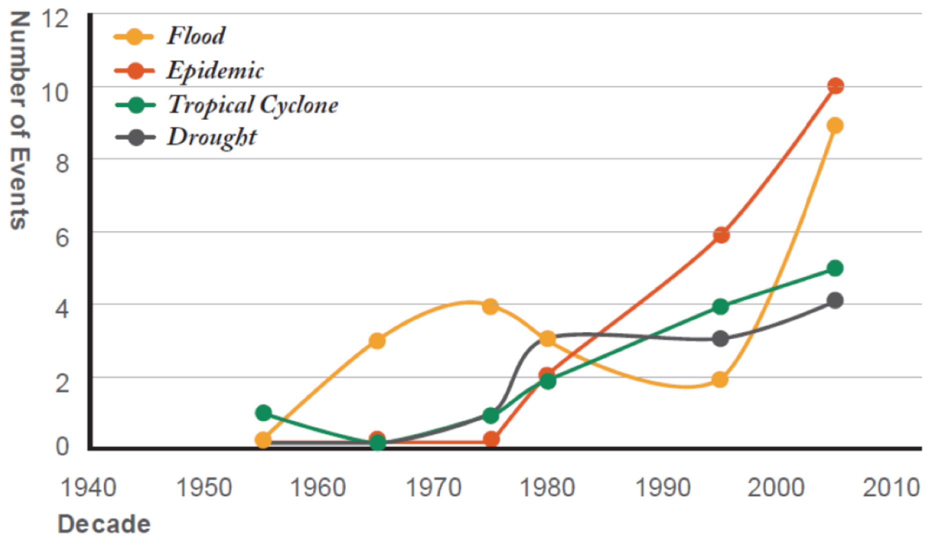
Some additional observations from the table include:

- The nature of each storm was different and as a result different sectors are being affected with each storm;
- During the past 22 years, there were three storms exceeding the 1:50 year expected return period with two of these exceeding the 1:100 expected return period;
- There is some indication that the asset damage is decreasing over time due to Samoa adopting more resilient options, although this could be owing to changes in storm patterns.

Some countries may even be impacted by a number of specific climatic changes. A vulnerability assessment of Mozambique showed an increase in floods, tropical cyclones, and droughts (Refer to Figure 1.3). An alarming relationship is also shown between the increase in climatic events and the increase in human epidemics.

Overall, climate change impacts are grouped into two categories – slow changes to average temperatures/rainfalls, and an increase in the frequency of large shock events. The following section details the specific impact on road infrastructure.

Figure 1.3: Total number of the four common events occurred in the different regions; Mozambique (COWI, 2010)



1.2 The Impact of Climate Change on Road Infrastructure – Slow Changing versus Shock Events

Road networks are the socio-economic backbone of any community. They provide access and movement of people and goods that fulfil all the functions necessary for people in a community to live and prosper. Roads mostly consist of natural gravels in combination with other materials such as asphalt and concrete. The design of the pavements and materials takes account the natural impact of the environment. Engineers are well aware of the negative impact water ingress has on pavements and design the pavements and associated drainage assets to counter this impact. Likewise, asphalt and other surfacing materials are designed for prevailing climatic conditions including rainfall and expected ambient temperatures expected during the design life of the surface.

Both rainfall and temperatures are starting to vary beyond the accepted design envelopes for the design methods of road pavement, surfacing and drainage structures. While slow changing environmental impacts put strain on the performance of the road network, a more significant impact is often observed from shock events of weather patterns. Historical design methods expect shock events to exceed the design parameters accepting that these events are normally infrequent. Yet, the previous section has indicated these shock events to be increasing in frequency and intensity – such that roads are subject to more extreme events within their design life. Simply accepting these events to exceed the design capacity of roads and structures is not a sustainable option any longer with the consequence being both a shortening of life cycles and/or temporary loss of accessibility along the road. Table 1.2 lists the main climate change events expected in the Nordic countries and how these impact on the road infrastructure.

Table 1.2: How the Climate Could Impact on Roads (NDF, 2016)

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Foggy days	• Traffic hindrance and safety • More smog

The NDF (2016) report also lists a number of mitigation or adaptation techniques to combat some of the impacts listed in the table above. The asset management approach incorporating some of these techniques is discussed further in following sections.

1.3 Objectives of Technical Report

The aim of this technical note is to explore the opportunities for integrating climate change into road asset management. Specific objectives are to:

- Review the entire asset management process in the context of how climate adaptation measures could be incorporated;
- Explore specific techniques related to data collection and decision making that fits within the problem domain of climate adaptation; and,
- Identify the future development issues that will assist seamless integration of climate adaptation into asset management processes.

2. Integrating the process of Asset Management in the Context of Climate Adaptation

2.1 Traditional Asset Management Process

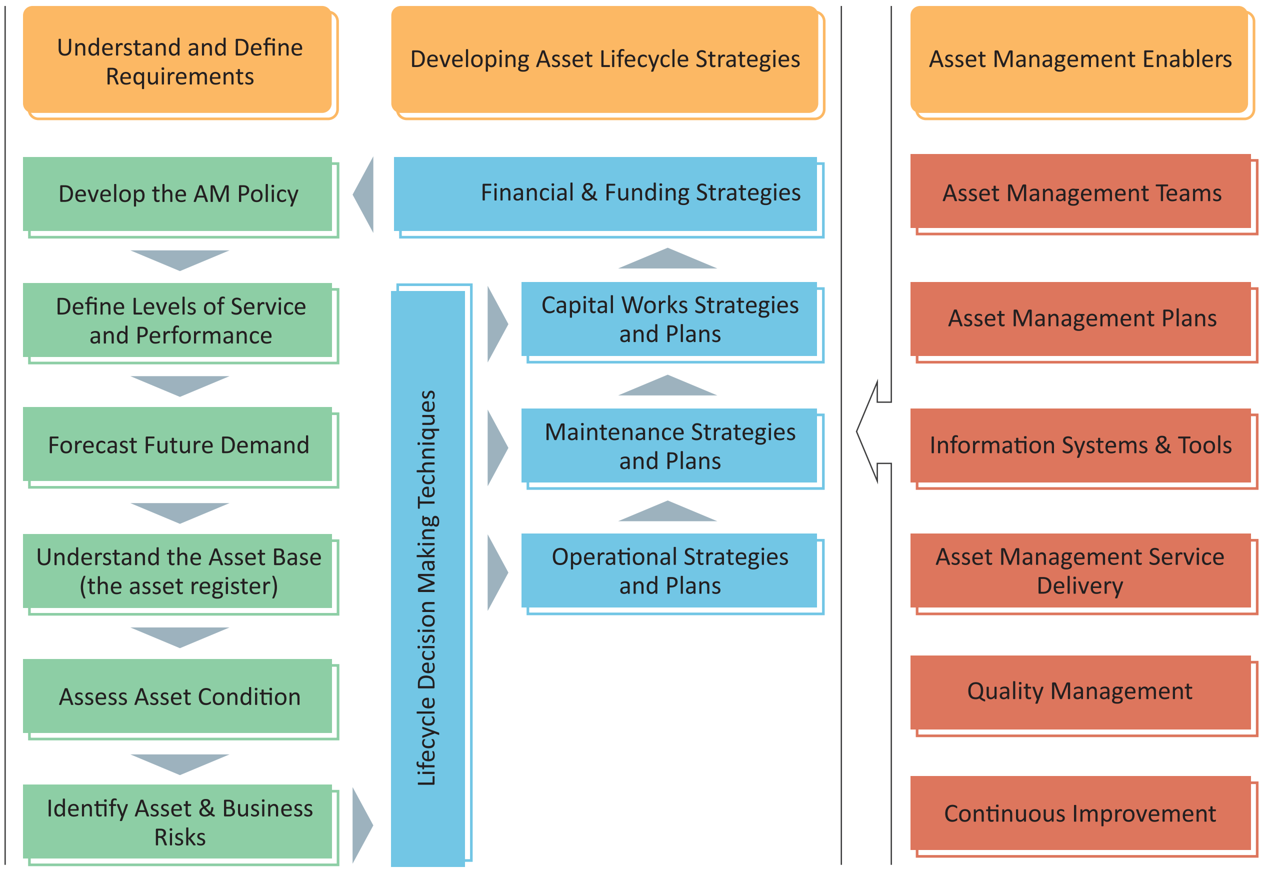
There are many definitions for asset management, all highlighting the importance of asset management to deliver an acceptable level of service. One example definition is:

> *Transportation Asset Management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives.*
>
> *Source: AASHTO Subcommittee on Asset Management in January 2006*

Considering the definition of asset management, it is only logical that asset management would be an effective vehicle for driving appropriate climate adaption measures for countries. Comprehensive asset management results in understanding the resilience of the network and striving to deliver the required level of resilience for the least cost. However, many road authorities are not well positioned to incorporate climate change into their asset management practices and processes as a result of not understanding the magnitude of the consequence; not understanding the issues involved; not having the data to implement change; or simply having other more pressing demands on time and resources. Overall it is considered that much more could be done through asset management in creating a better future through appropriate infrastructure strategies.

Figure 2.1 shows the traditional asset management process that are being grouped into “understanding the requirements”, “development of strategies” and “asset management enablers” For each of these groups and each item listed under these groupings, there are actions that can be taken to embed climate adaptation measures into asset management planning. The lay-out of the asset management process within Figure 2.1 forms the structure of the remainder of this report.

Figure 2.1: Asset Management Process (NAMS. 2011)

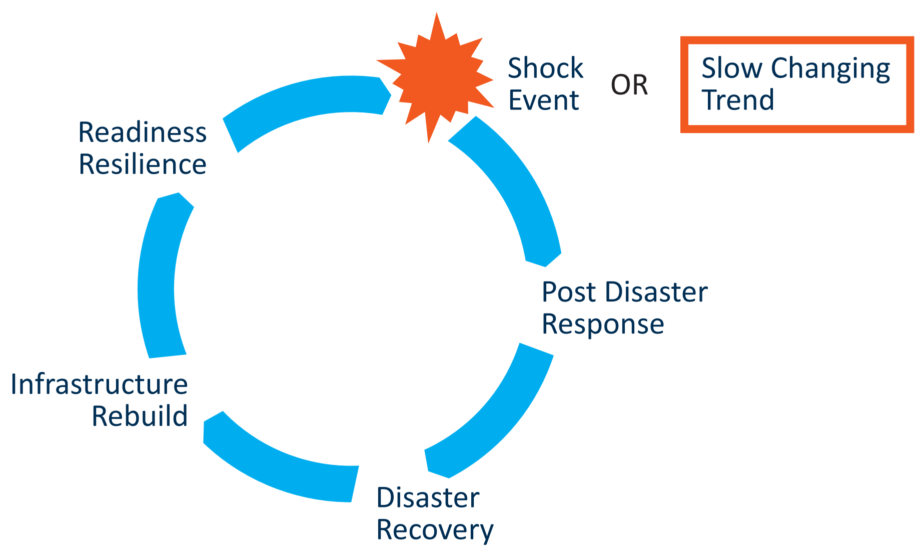


2.2 Asset Management Needs Created through Climate Change

There are two distinct climatic changes that should be allowed for in asset management (Refer to Figure 2.2):

1. Road infrastructure will be impacted through slow changing climatic trends such as increasing temperatures and higher rainfall and/or longer drought periods. These changes will impact on the long-term performance of infrastructure thus automatically impact on the entire asset management planning activities. For the purpose of this report, all asset management processes and activities related to the slow changing environments will be under improving resilience and readiness activities of climate adaptation; and,
2. Shock events often resulting in major parts of road networks being destroyed. Effective use of asset management processes in advance of the event, during the event and within the rebuild planning stages, assist not only in more efficient rebuild scheduling but also assist in the long-term strategic investment decision making processes.

Figure 2.2: The Climate Adaptation Cycle



In relation to the asset management process in Figure 2.1, shock events are primarily addressed through the identification of risks, and the operational and maintenance plans; while slow changing climatic trends encompass the entire asset management process.

The World Bank has defined the four pillars of climate adaption in Table 2.1 as being Sectoral & Spatial Planning; Resilient Infrastructure Solutions; Enabling Environment; and Post-Disaster Risk & Recovery Support. All four of the pillars indicated can be addressed through using asset management processes and enablers. In the same World Bank report, the monitoring techniques and adaption strategies were further explored to identify the asset management system component that addresses the needs from a climate adaptation perspective (refer to Table 2.2). Subsequent sections explore these asset management components in more detail.

Table 2.1: The Four Pillars of Climate Adaption (McPherson and Bennett (2005))

	Sectoral and Spatial Planning	Resilient Infrastructure Solutions	Enabling Environment	Post-disaster Risk and Recovery Support
Objective	Upstream vulnerability assessment for climate change and other challenges	Investments in physical infrastructure or new technologies designed to reduce the impacts of current and future climate risks and ensure robustness, redundancy and resilience. This can include community based adaptation.	• Policies, plans, codes and reforms designed to reduce the impact of current and future climate risks, or enable future adaptation. • Investments in human, institutional, and technical capacity to raise awareness, analyze, and cope with current and future climate risks. • Investments in systems that collect, organize, store and analyze climate data, and capture and share lessons. • Funding and resources allocated to deliver and maintain resilient infrastructure systems	Ensuring short and long term climate change risk and resilience is integrated into rebuilding efforts
Delivery	Examples: • Urban planning • Transport master plan • Road network plans	Examples: • Non engineering and engineering solutions • Maintenance	Examples: • Codes and standards • Institutional coordination • Awareness programs • Budget planning • Contingency planning • Improved hydro met information • Monitoring for resilience	Examples: • Post disaster needs assessment • Building back better • Strengthened codes and standards • Across government & donor coordination
Bank Piloted Tools and Approaches	• Economics approach to vulnerability assessment • Engineering approach to vulnerability assessment and resilience planning • A systematic condition assessment of infrastructure through vulnerability and risk assessment • Vulnerabilities assessment using socio-economic criticality and flood susceptibility in the transport network	• Screening tools for climate and disaster risk for use in early stages of investments • Decision-support systems for evaluating and including impacts on economic and social continuity of alternative transport network investments • Cost-risk assessment framework under a given climate scenario • Decision-making under uncertainty (DMU)	• Infrastructure planning and maintenance through a vulnerability lens • Tracking climate mitigation and adaptation co-benefits • Socio-economic resilience indicator	• Building resilience in the transport sector after disaster • A systematic condition assessment of infrastructure through vulnerability and risk assessment

Table 2.2: Asset Management Components of Climate Adaptation (Ebinger and Vandycke, 2015)

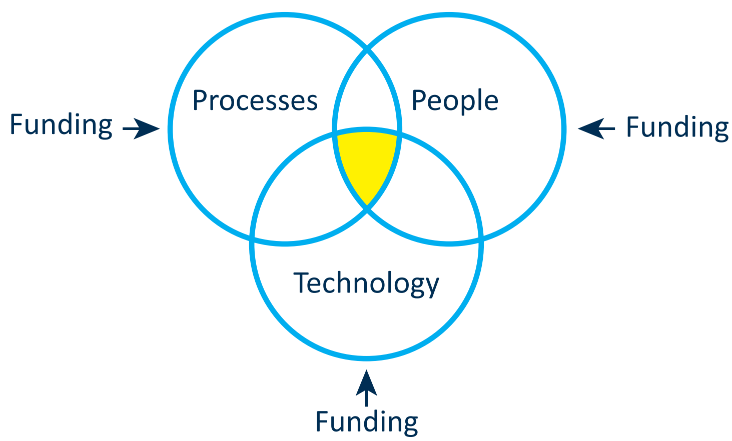
Asset Management System Component	Monitoring Techniques and Adaptation Strategies
Goals and Policies	Incorporate climate change considerations into asset management goals and policies. These could be general statements concerning adequate attention of potential issues, or targeted statements at specific types of vulnerabilities (e.g., sea level rise).
Asset Inventory	Mapping of infrastructure assets in vulnerable areas, potentially using GIS. Inventory critical assets that are susceptible to climate change impacts.
Condition Assessment and Performance Modelling	Monitor asset conditions with environmental conditions (e.g., temperature, precipitation, winds) to determine if climate change affects performance. Incorporate risk appraisal into performance modelling and assessment. Identify high risk areas and highly vulnerable assets. Use "smart" technologies to monitor the health of infrastructure assets.
Alternatives Evaluation and Program Optimization	Include alternatives that use probabilistic design procedures to account for the uncertainties of climate change. Possible application of climate change-related evaluation criteria, smart materials, mitigation strategies, and hazard avoidance approaches.
Short- and Long-Range Plans	Incorporate climate change considerations into activities outlined in short and long range plans. Incorporate climate change into design guidelines. Establish appropriate mitigation strategies and agency responsibilities.
Program Implementation	Include appropriate climate change strategies into program implementation. Determine if agency is actually achieving its climate change adaptation/ monitoring goals.
Performance Monitoring	Monitor the asset management system to ensure that it is effectively responding to climate change. Possible use of climate change-related performance measures. Use "triggering" measures to identify when an asset or asset category has reached some critical level.

3. Asset Management Policies and Strategic Aspects

3.1 Driving Successful Implementation from an Executive Level

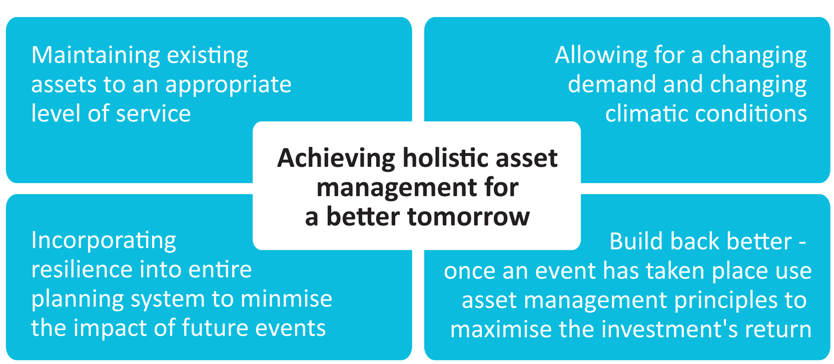
McPherson and Bennett (2005) investigated the key success factors of Road Management Systems (RMS) that could be categorised into three groups: processes; people; and technology, all being adequately support by sufficient funding (Refer to Figure 3.1).

Table 2.2: Asset Management Components of Climate Adaptation (Ebinger and Vandycke, 2015)



As with other studies, McPherson and Bennett (2005) also emphasised the importance of having the executive level of countries, agencies and organisations specifically driving the successful adoption of asset management processes and systems (now also including climate adaptation aspects). The conclusions form this study is directly relevant to asset management today and tomorrow with an increased emphasis on taking account of the pressures from the environment and providing services to an ever-changing population. Figure 3.2 presents a framework of such a holistic asset management process that takes account of the challenges we are facing today and increasingly tomorrow.

Figure 3.2: How Climate Adaptations Needs to be Part of a Holistic Asset Management Process



> *Executives and managers would be demonstrably committed to the system, both in their relations with external stakeholders and internally in their agency through good management principles. Policies would explicitly state the goals and objectives of the organization with regard to road asset management, and procedures would detail exactly how the RMS would be used to achieve these goals.*

Some specific recommendations from the McPherson and Bennett (2005) report worth repeating are:

- *Funding: Have annual budgets in place for data collection and operation of the RMS. Even if this initially requires donor funding support, there should be a phased increase in local budgeting to ensure that the RMS is self-funding within a given timeframe.*
- *Introduction of an RMS by itself is not a guarantee that it will be used, or that it will be successful. The agency must also follow basic asset management principles. Strong involvement of executives and managers prior to and during the implementation of the system is absolutely necessary.*
- *Clear and explicit RMS planning and programming cycle/schedule developed with clear deadlines of and correlation between main tasks*
- *Annual Reports/Business Plans should be prepared, using 'Asset Value' and other Key Performance Indicators derived from the RMS. This is an executive and managerial responsibility. It also helps put focus on the RMS itself, since it provides the data and improves the chances that budget and funds are available to run the system.*
- *Institutional support consisting of high ranking decision-makers fully-committed to the asset management/asset preservation 'philosophy'.*
- *Regular briefings should be given to ministers and other high government officials on the importance of asset preservation, and what is being done to make sure that the preservation of the road infrastructure is dealt with satisfactorily*
- *Have specific and realistic key performance indicators, targets to measure asset value and to preserve/enhance that value. Monitor those targets, and assess at the end of each year whether they have achieved them or not, and take appropriate action. By publishing this information in Annual Reports, they are accountable to it.*
- *Have policies and procedures in place for data collection, and for quality assurance of that data.*
- *Technical (internal and/or external) auditing must be carried out on data and systems, and the recommendations acted on.*
- *A program of Continual Quality Improvement is also critical. No system is static. All systems can be improved.*

3.2 Governance

3.2.1 Integration of Climate Adaption into Asset Management

In response to legislation that detailed more formal asset management expectations in countries such as New Zealand (Local Government Act, 2002) and the USA (MAP-21), local road agencies have created dedicated teams who were responsible for asset management planning and processes. The creation of asset management teams did not only ensure that there was sufficient focus on achieving the delivery of asset management plans and strategies, but it also ensured that a common team was planning across all engineering disciplines.

These dedicated asset management teams did not undertake all aspects of asset management in all parts of an organisation as part of the asset management process. Instead, the asset management teams ensured a common understanding was in place and took responsibility for ensuring that all parts of the organisation were aware of their respective responsibilities from an asset management perspective. Similar approaches have been successfully adopted by all manner of organisations for addressing health and safety requirements.

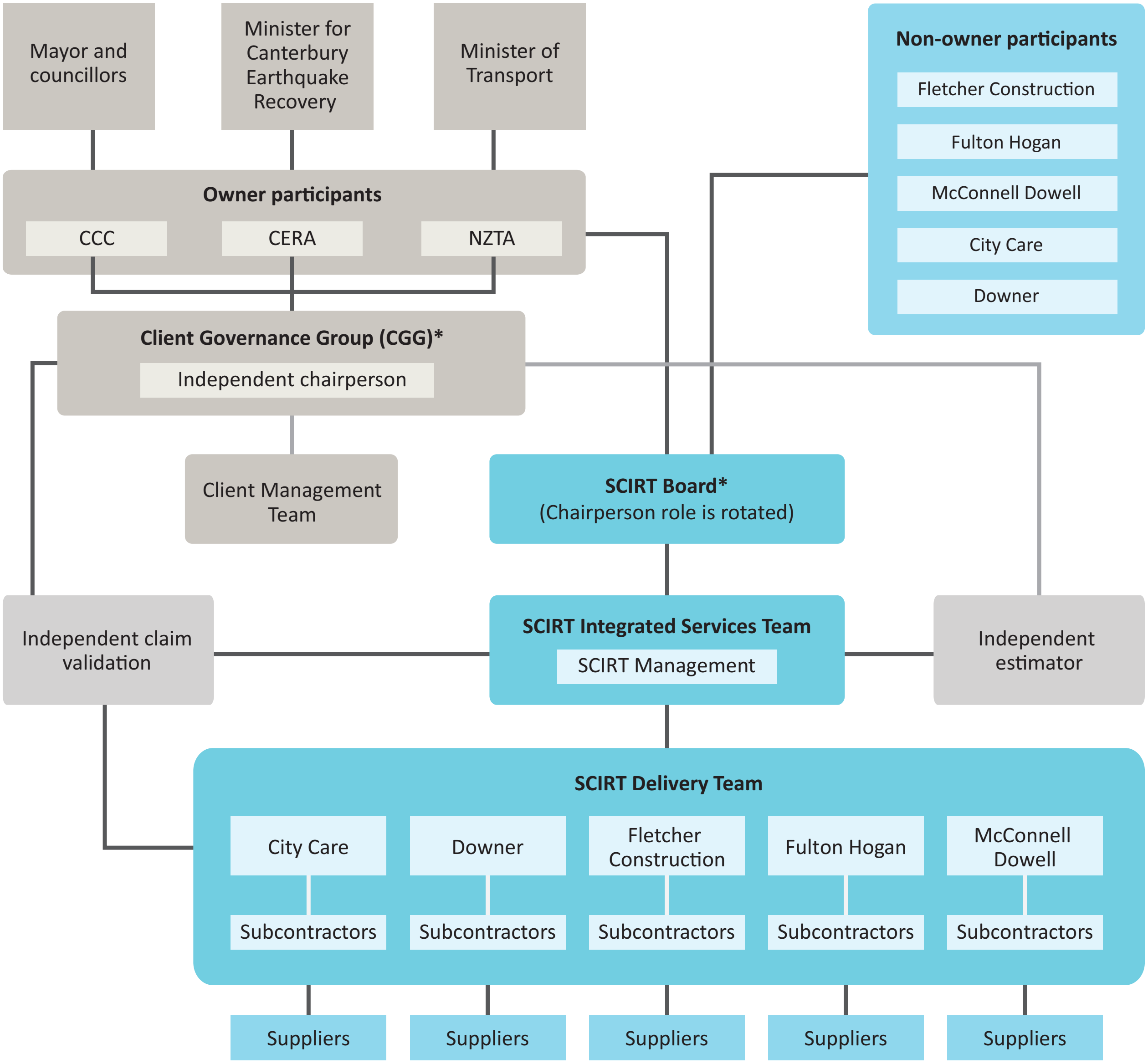
The same principle applies when venturing into integrating climate adaptation into asset management. The asset management process is already a complex process that requires the input from a multi-disciplinary team. This is further complicating by introducing climate adaptation aspects into the planning processes. It is therefore recommended to have a dedicated asset management team that also include experts in climate adaption needs and technologies.

3.2.2 Governing Major Rebuilding Programmes

Normal governance structures simply cannot cope with major rebuilding planning and activities. The reality is that the governance structure of road agencies is normally structured to fulfil the “business-as-usual” operations. Following a major shock event, a completely separate and dedicated governance structure needs to take full ownership of all aspects related to the rebuilding programme.

For example, following the Christchurch earthquakes in 2012 and 2013, the city was faced with a significant rebuild programme of the CBD and infrastructure within the entire city’s boundaries. For such a significant rebuilding process an additional governance structure had to be set up to manage the investment, programming, decision process and contracts. **The Stronger Christchurch Infrastructure Rebuild Team (SCIRT)** was established as an alliance between the Christchurch City Council, the NZTA Transport Agency, the New Zealand Government and the five major infrastructure contractors from New Zealand that participated in the rebuilding process. The Alliance was managed by a Board representing each of the Alliance partners. Separately, a Client Governance Group consisting of representatives of the government, Christchurch City Council and the New Zealand Transport Agency provided direction to the Alliance on scope and programme priorities. A similar governance structure could also be set up in situation where an external donor or funding agency assists a country during a rebuilding process.

Figure 3.3: Organizational Structure of SCIRT, Christchurch New Zealand (OAG, 2013a)



The responsibilities of the Client Governance Group were (OAG, 2013a):

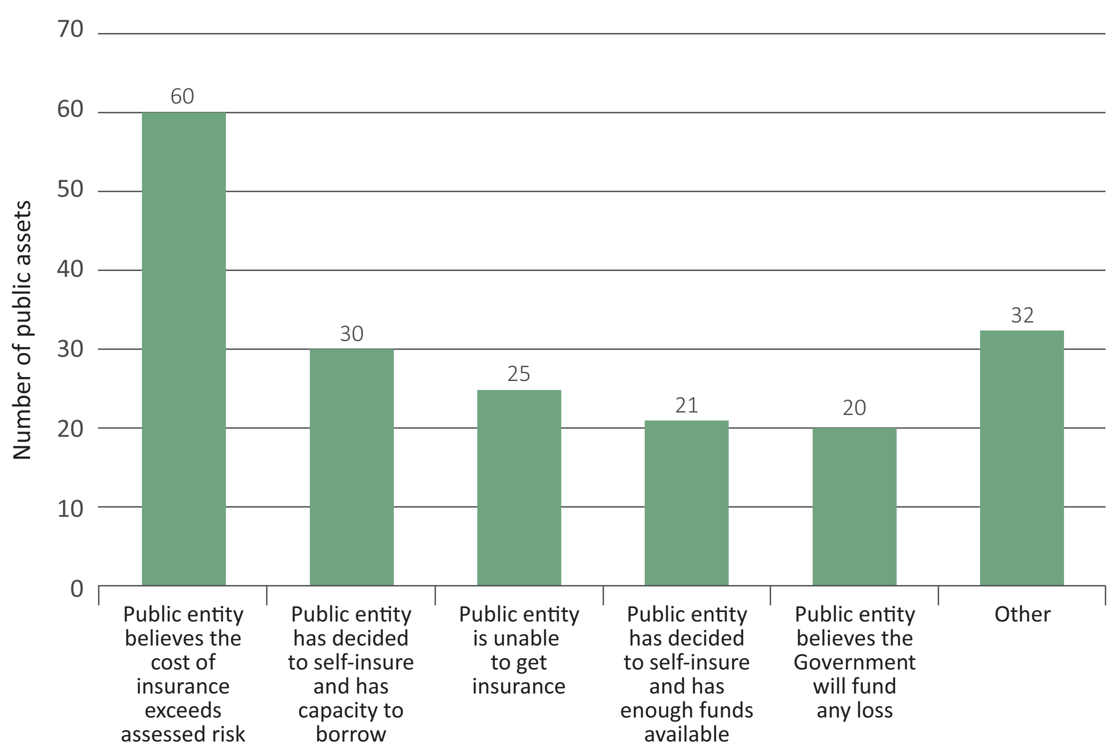
- *The CGG's role is to produce and maintain a governance framework for delivering the Infrastructure Rebuild Plan. This includes providing a process for escalating issues and making decisions about infrastructure, and appointing subcommittees as needed.*
- *The CGG has several strategic and planning roles. It is to inform the development of wider recovery strategies and to ensure that work delivered under the SCIRT alliance is consistent with the wider recovery strategies. Also, the CGG has to prepare a process for approving decisions about betterment and exceptions to standards. External factors can affect the work of the Alliance, and the CGG is responsible for considering and responding to the effect of those factors.*

- *All members of the CGG are directly or indirectly funders of SCIRT. Therefore, the CGG approves the annual work programme and budgets, and co-ordinates SCIRT's funding requirements. It also reviews audit reports and the implementation of controls.*
- *The CGG is responsible for meeting the clients' obligations under the Alliance Agreement. It monitors SCIRT's progress and budget through annual and monthly reports that cover progress, trends, and performance against milestones and performance objectives. Importantly, the CGG is to ensure value for money and manage prioritization of the rebuild programme to be delivered by SCIRT within the available funding.*

3.3 Funding, Policy and Legislation

Some infrastructure agencies around the world would take out insurance cover against natural disasters. However, it often happens that the insurance is not sufficient to cover all damages as many disaster damages are more widespread compared to estimated "worse cases". Following the Christchurch earthquake during 2013, the significant shortfall in insurance has resulted in New Zealand Government having to significantly assist with the rebuild costs. As a consequence, the Office of the Auditor General conducted a study into the level of insurance cover amongst local government and concluded that a large number of the agencies were not insured (Refer to Figure 3.4).

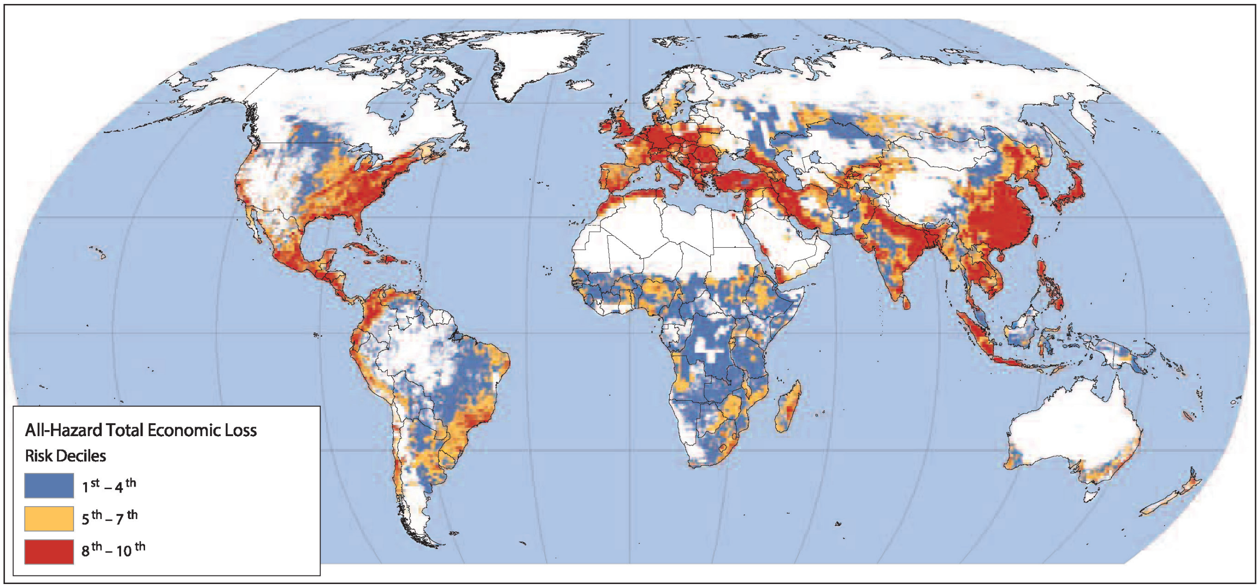
Figure 3.4: Reasons why Some Local Government Assets have No Insurance Cover (OAG, 2013b)



The cost of disasters in the future could well be astronomical unless prior mitigation measures are put in place to minimise the impacts. Figure 3.5 shows the global estimated economic loss due to all disaster hazards. It is safe to assume that only a small portion of the infrastructure indicated in the high-risk areas would be insured. This is mostly where governments, donor organisations and relief funds assist those affected by disasters.

> *“When a disaster hits, where is the money going to come from?”*

Figure 3.5: Estimated Economic Loss due to Disaster Hotspots - All Hazards



The reality is that pre-empting disasters, planning and mitigating some of the risk would be far less costly than trying to recover from an “unforeseen” disaster. Therefore, it is recommended that countries and agencies prepare for disasters at this level through:

- Planning the funding resources that could be utilised following a disaster including insurance, cash reserves, and agreements in principle with external financiers. Where these are not in place, then it is likely that funds will be diverted from normal maintenance and renewal activities, into the recovery activities – which in turn places the wider network at a higher risk of deterioration. Understanding this potential in advance is essential to determining where to source funds for the recovery should come from;
- Policy has to be developed in order to:
  - provide for adapting planning processes to take account of climate change;
    have policies in place in mitigating disastrous events;
  - develop policies for dealing with all aspects related to disaster response, including emergency protocols, recovery governance and rebuilding organisation;

- Legislative preparedness: Often, policy that sources and distributes funding needs to be supported and controlled through appropriate legislation. In most cases, the nature of events would be unknown until it occurs and pre-empting the required legislation may be difficult to foreseen. However, if only a process of passing emergency legislation is enabled, it may ease the process following a disaster; and,
- Agencies should focus on creating analysis capabilities to assess options for resilience. The aim would be to minimise investment over the long run in addressing slow changing climatic impacts, preparing for disasters and rebuilding following disasters (Refer to Section 6).

A key learning point from many disasters is that trying to develop policies while immersed within disaster does not always lead to sound decision making. Policies of who would be entitled to compensation under various scenarios should be developed rationally; independent from the disaster taking place, rather than being developed in the midst of a rebuild programme.

3.4 Procurement

Procurement is one of the most important delivery mechanisms for an effective implementation of an asset management strategy. In the context of climate adaptation, the area of procurement is such a broad subject matter that it warrants a full study of its own. Table 3.1 list some procurement actions that may be considered by road agencies in the context of climate adaptation.

In addition to the actions in the table that can be worked into existing contracts, there is also the potential to have 'on-call' emergency response contracts with industry that cover typical urgent response tasks. Such contracts can sit in addition to either in-house force account or private sector contractors that are involved with the day-to-day maintenance of the network.

Figure 3.5: Estimated of Total Economy Loss due to Disaster Hotpots All Hazards (Dilley at al., 2005)

Adaptation Stage	Action
Addressing resilience and slow changing climate impacts	Include specific climate adaptation strategies e.g. in China the Bank project OPRC project has two elements: 1. Trial different asphalt mixes. 2. Increase the capacity of drainage facilities in conjunction with other works on the network. Include the ability into contracts to incentivise innovation for climate adaptation technologies
Post disaster Event Procurement	• Long-term contracts should include performance measures on key vulnerabilities • Long-term contracts should include clauses to deal with shock events • Pre-developed contract templates should be prepared to deal with post disaster works • Policies and legislation to allow for most efficient procurement formats and strategies • A governance structure to be in place for managing multi-contracts and administration. (See Section 1.1.1)

4. Asset Information Management

4.1 Background to Asset Management Data

Robust data, data management and information management systems are core to all the asset management activities. This section will not go into any detail on the data collection, management or storing aspects related to "business as normal" asset management. The aim of this section is to highlight any potential implications on current data practices from integrating climate adaption considerations into asset management. A list of the asset management use of asset data that would also be relevant for climate adaptation integration are (AUSTROADS, 2016):

- Network extent and definition including geospatial maps;
- Asset valuations;
- Risk Management;
- Condition/performance monitoring and management;
- Demand Management;
- Access management;
- Works cost recording and reporting;
- Forecasting decision making tools; and,
- Forward works programming and planning.

The characteristics of data to note are summarised in Table 4.1.

Table 4.1: Characteristics of Data (Based on Dinshaw et al., 2012)

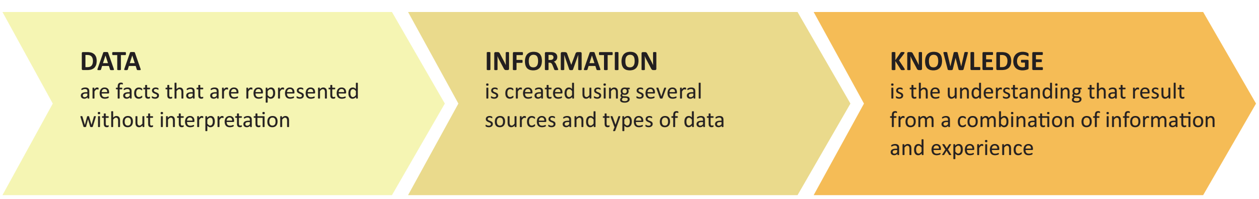
Characteristic	Data Items	Examples
Data domain	Infrastructure data	The road information including: inventory, condition, traffic, pavement and surface data
	Socio-economic data	The socio and economic information in terms of how a community functions and earn a living
	Biophysical data	The physical environment and natural world such as stream flow, soil quality end ecosystems
	Climatic data	The variables of the climatic system such as rainfall, temperature humidity pressure and wind
	Historical Data	Data that has been collected on past behaviour and achievement

Characteristic	Data Items	Examples
Temporal Character	Current Data	Data collected at present and real time data
	Predicted Data	Forecasted data on models and possible future scenarios
	Observed Data	Data that were collected by means of various technologies. Although unaltered different levels of accuracy and quality is accepted.
Data Origin	Modelled Data	Data that cannot be observed like future events.

4.1 Background to Asset Management Data

Asset managers often make a mistake of defining data needs on the basis of what they are able to collect. A far more effective manner to determine data needs is to consider the ultimate use of the data and often it centres on the decisions that have to be made and what knowledge or information is required to make those decisions. Figure 4.1 illustrates the progression from data to knowledge, accepting data without any interpretation is often of little value. Also, knowledge is based on a combination of data from various sources plus experience.

Figure 4.1: From Data to Knowledge (Dinshaw et al., 2012)



The purpose of data use in asset management is listed in the previous section. It is expected that climate change may have an influence on all the outcomes of the asset management activities listed. As for specific climate adaption data, three distinct areas are identified by Dinshaw et al., (2012):

- **Problem definition** – Qualify and quantify the specific issues climate adaptation needs to resolve. Data that would enable vulnerability assessments, assessment of risk exposure and future impact studies;
- **Adaptation options analysis and selection** – Any technology, processes and/or design addressing climate adaptions needs to undergo either economic, financial or socio-economic assessments. Sufficient data in terms of the exact impact and life expectancy of these technologies would be essential for these types of analysis; and,

- **Monitoring and Learning** – Although sufficient data exist on the climate change itself, little data and knowledge exist on the exact impact of climate change and the success of adaptation in mitigating some of these risks. There is a mammoth data need in the area of climate adaptation impact data in order to build onto the knowledge base of this topic area. At the simplest level this includes the recording of the magnitude of climate related events (e.g. depth and duration of flooding, along with rain fall data) such that models can be developed and calibrated to local conditions. While at the more complex level, the data includes detailed analysis of temperatures and associated changes in pavement performance over time.

4.2.1 Data Needs for Improving Resilience and Adaptation

In order to improve the overall systems resilience, much can be achieved through keeping and storing the right type of data. Data fulfil two distinct functions in improving resilience including:

- Data can contribute towards understanding vulnerabilities on a network and also highlight areas that could be address to mitigate these risk; and
- Secondly, by storing the right kind of data in a useful format, data could significantly assist in the recovery and rebuilding processes following a shock event.

Table 4.2 lists some data items that could assist in the improvement of resilience. Please note that the purpose of the table is not be a complete list of data required for day-to-day asset management activities, it rather just highlights specific resilience improvement data items.

Table 4.2: Data Needs to Improve Resilience of a Network and Systems

Data Items	Application	Normally Collected	Data Domain	Who should store/ collect it?
Network definition – Geospatial Data	• "The power of "knowing where it is": • Displaying geospatial information of the network in relation to climate risk (Vulnerability assessment); • Display in-relationships between infrastructure types; • Planning and management of "life-lines". • Preparing for post-event planning ("knowing what infrastructure existed and where everything was prior to a shock event")	✓	Infrastructure data	Specific road network owners, regional and national datasets
Network criticality data	Identified critical asset (life-lines) that would be maintained to a different standard compared to the rest of the network	✓	Infrastructure data	Specific road network owners, regional and national datasets

Data Items	Application	Normally Collected	Data Domain	Who should store/ collect it?
Condition/failure risk/ structural health data	Parts or road links that could be prone to failure or at risk due to insufficient drainage provision	x	Infrastructure data	Specific road network owners
Data required for managing specific risks (e.g land-slides and rock falls)	Due to climate change such as wetter or dryer soil conditions some continuous risk such as land-slides and rock falls becomes more hazardous and continuous monitoring, reporting and publication of information becomes important	x	Infrastructure data	Specific road network owners (Reporting could be on public websites)
Rainfall/Storm and/ or other weather impact data on infrastructure	What specific impact on infrastructure resulted from any weather activity, for example, roadways that have been flooded, areas prone to water related failures etc.	x	Infrastructure data	Specific road network owners
Road function/ community socio-economic or cultural activities	Used for prioritising/ optimising maintenance and capital investment pre-and-post shock event	x	Socio-economic data	Regional and national datasets
Physical environmental information such as soil types, waterways and streams	Overlay climatic information in order to undertake vulnerability assessments	✓	Biophysical data	Regional and national datasets
Historical and current weather patterns	Understanding storm patterns and return periods – use for designs and vulnerability assessments	✓	Climatic data	Regional and national datasets

4.2.2 Post Disaster Data Needs

There is no stronger emphasis on the importance of data than having to start planning post disaster recovery or rebuilding processes without any data. It is equally important to have robust data of the network prior to an event as it is to have sufficient and appropriate data post shock event. These two temporal datasets give the required perspective on a GAP analysis of infrastructure needs being:

- What infrastructure services was in place prior to the event;
- What has been damaged during the event; and,
- What needs to be replaced under given geographical or physical constraints for post disaster environment and/or in cognisance of potential future re-occurrence of shock events? For example, infrastructure may not be re-established in areas of liquefaction or areas where future flooding is certain.

Most disasters are followed by a period of urgency in order to get the data collection, planning completed and recovery and rebuilding processes commencing as soon as possible. Some of the drivers towards rapid data collection and planning are:

- An urgent period of the response and recovery stage is to identify locations of on-going hazards to the community. These areas need to be cordon off or neutralised for further harm to the community;
- The agency has a limited time period to appeal for additional funding and/or relieve aide, knowing the exact extent of damage strengthen the case for relieve funds;
- The recovery includes the urgency of getting critical assets functioning quickly, again driving the needs to have an understanding of the damage to these asset groups;
- Despite media focusing on the tragic side of any disaster, what is often of greater importance is to get the local economy up and running as soon as possible. With infrastructure being the back-bone of the socio-economic environment, it is critical to get the infrastructure functioning as soon as possible.

Little evidence was found on the specific stages of data collection following a shock event but it is recommended that this should be done in two stages of:

- **Stage 1: Initial screening** for determining the functionality of the road network in terms of access and potential hazards. For example, some of the items being recorded at this point may include:
  - Evacuation routes/highways being blocked and/or over congested;
  - Road closures plus reason for closure (broken/abandoned vehicles, other objects on the road or unpassable damage;
  - Bridge damage/closure;
  - Flooding as a result of event or secondary flooding due to broken pipes;
  - Risk of secondary spills, leaking gas pipes or fallen power lines; and;
  - Pedestrians or people evacuating on foot.
- **Stage 2 – Detail assessment or repair needs** – this stage would do more detailed damage assessment of targeted infrastructure in order to determine the actual damage and repair/ rebuilding requirements. This assessment would also include feasibility of emergency repairs that may temporarily restore the functionality of the route with some more intensive restoration happening at a later stage.

The following sections detail some technologies related to the data collection and management of the data.

4.3 Closing the Data Needs Gap

The prior sections have shown that the bulk of data required for climate adaptation is already part of the data requirements for business as normal asset management. Unfortunately, it is also known that in most countries having robust and complete data for asset management planning remains an on-going challenge for road agencies. In some cases, the value of investing into data collection may even be questioned. However, there is no smarter investment than ensuring sufficient information is available for the required decision making processes. The value of sufficient information is more amplified in the context of adapting to climate change.

The priorities for closing data gaps are as follows:

1. Ensure sufficient and robust data is collected for day-to-day asset management purposes (See Bennett et al., 2007);
2. Undertake a criticality analyses on main routes;
3. Including geospatial element to all data;
4. Start storing climate data;
5. Gather and store vulnerability information;
6. Gather specific adaptation information;
7. Create capabilities for rapid data collection processes.

> *Better data and information assist in better decision making. Investing into the collection of relevant data and information is the first and foremost investment into climate adaptation.*

4.4 Data Security/Resilient Systems

Cyber security has become an important resilience topic area, similar to that of resilience of the physical asset. Our dependence on computer and web technology has left us vulnerable to this technology going off-line for an array of potential threads or events. It is therefore particularly important to consider computer and web technology as part of the resilience planning of infrastructure. Its interdependency with other infrastructure is a significant part of understanding the over-all system's vulnerability. For example, all cyber technology is completely dependent on power thus power supply and distribution networks. At the same time, cyber technology is often controlling assets groups through automated processes including:

- Intelligent transport systems;
- Public transport control systems for rail, ports and airports.
- Power and water supply systems; and,
- Financial systems.

The relevance of system resilience and data security is two-fold:

1. The asset management processes need to incorporate the mitigation of both slow changing climatic impacts plus improve residence in preparation for potential shock events. Cyber and data security is at the heart of this mitigation; and
2. The dependency on pre-event data plus the ability to analyse post-event asset status rest upon the availability and access to the network data plus the planning systems.

The second point above emphasises the importance of off-shore back-up of both systems and data, plus the protocol of retrieving the data and system in an emergency event. Fortunately cloud technology has already solved much of the technical challenges for backing up systems but agencies still have to ensure that processes and protocols are in place for when needed – including how to access data stored in the cloud when telecommunications channels may be down during a major climatic event.

> *A common characteristic of data collection techniques related to climate adaptation and disaster events is its strong connection to geospatial positioning – "the power of knowing where it is"*

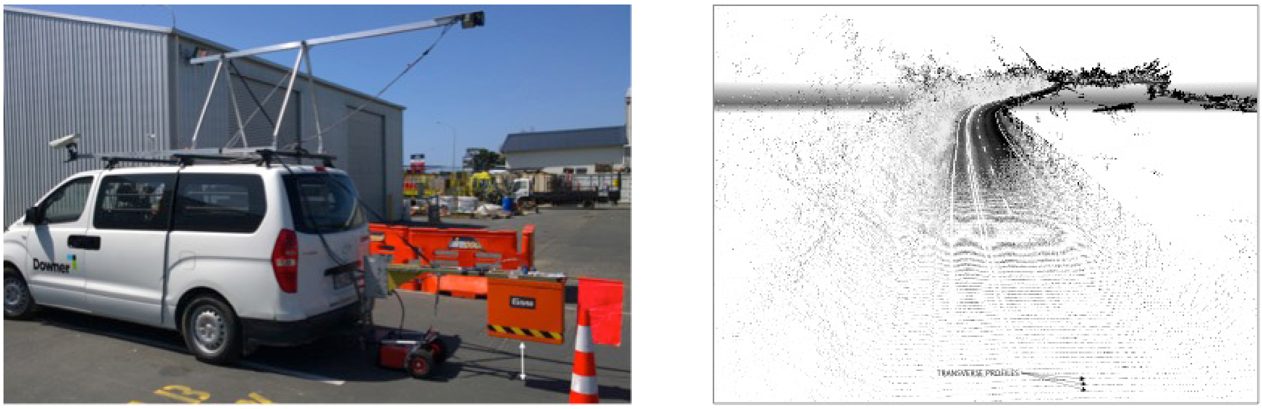
4.5 Data and Rapid Data Collection Techniques and Processing

Most data collection techniques used in asset management of roads would be directly applicable to the sorts of data required to incorporate climate adaptation. In most cases, current data collection practices only need a slight emphasis shift towards incorporating some of the required data items for climate adaptation (See Table 4.2). For example, a data area that has been highlighted to have greater importance would be comprehensive geospatial data for the network. Being diligent in keeping this up to date to the required information needs is essential. Also, greater focus on specific asset groups that are directly impacted or are mitigating impacts from the climate such as drainage, coastal protection structures and slope stability information needs to be collected to a level that allows adequate information to manage the functioning and effectiveness of these assets.

Figure 4.2 and Figure 4.3 show the survey vehicle and outputs from the moisture surveys performance on road pavements. Pavement performance is directly related to the moisture content that is managed through the provision of adequate drainage. Henning et al. (2014) has determined that a road with adequate drainage lasts 30% longer compared to the same road without adequate drainage. With an increase in rainfall, the potential moisture problem areas will have a significant increasing impact on road maintenance funding.

Managing the pavement moisture levels would become an effective mitigation measure to detect moisture issues early. Figure 4.3 shows the left-hand side of the road to have significant moisture build-up. Supporting scans and images suggest the water build-up is mostly likely originating from the side slope on the left-hand side of the road. For this instance, sub-soil cut-off drains in conjunction with adequate side drains would prevent future failures of this road length.

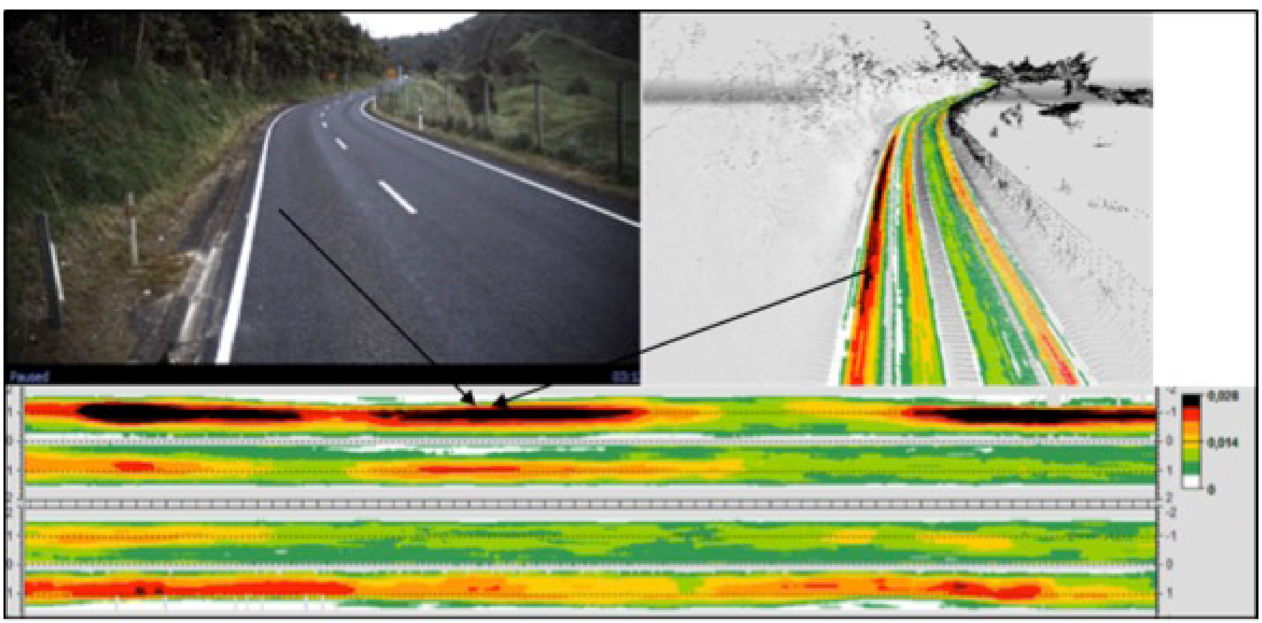
Figure 4.2: Surveying the Potential Moisture Issues on Road Pavements (Arnold et al., 2016)



Laser Scanner, video and GPR Survey

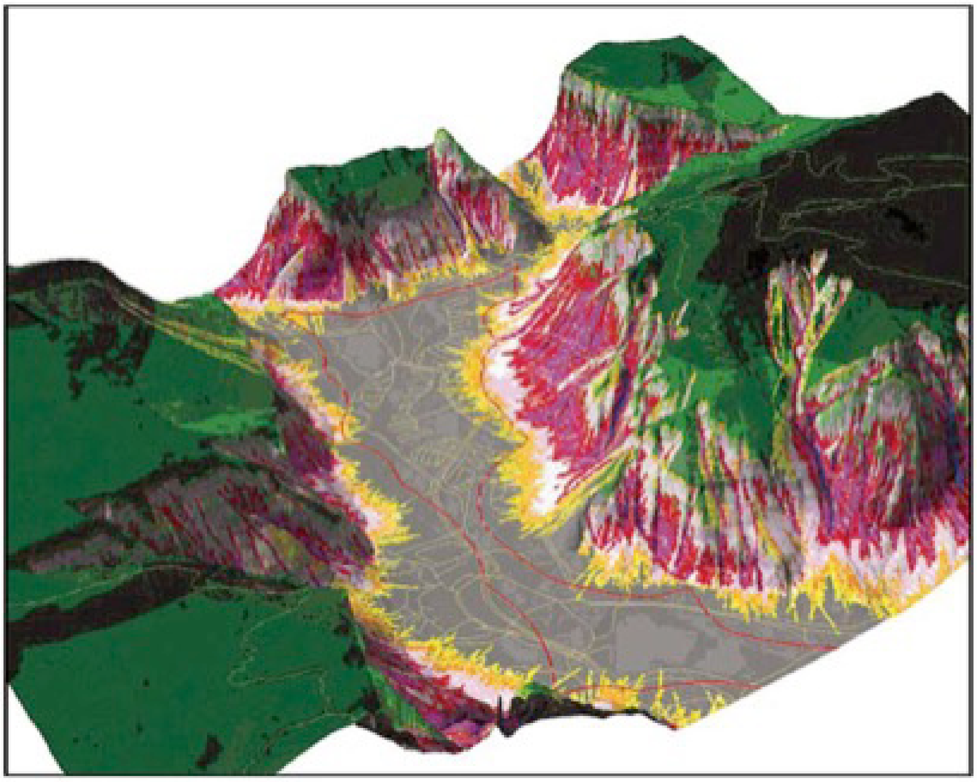
Scanning data

Figure 4.3: Outputs from the Moisture and Pavement Survey (Arnold, 2016)



Literature on other types of data collections, monitoring and reporting frameworks for example, for monitoring slope stabilities are readily available (McNuilty and Stevens, 2016) and (Wieczorek and Snyder, 2009). Figure 4.4 gives an example of a three-dimensional display of rock-fall hazards.

Figure 4.4: Three-Dimensional Display of Rock Fall Hazard (Guzzetti et al., 2003)



The most significant area of development would be in the rapid data collection techniques used for post disaster damage assessments. Some of the most common data collection techniques are summarized in Table 4.3. Jovel and Mudahar (2010) also describe the data collection process for damage assessment in more detail.

Table 4.3: Rapid Data Collection Techniques for Post Disaster Surveys.

Data Collection Technique	Description, Purpose an Application	Reference
Manual/Visual Assessments	Most commonly used for all disaster types. It is quick to mobilize and often more than adequate for initial damage and hazard identification.	World Bank, 2010
Geospatial Video and Photographic Data	Most commonly used for all disaster types. It is quick to mobilize and does provide accurate records of the actual on-site situation. These techniques do require a secondary processing stage of interpreting the data and translating it into useful planning information.	Mills et al., 2010

Data Collection Technique	Description, Purpose an Application	Reference
LiDAR Data Collection (Including drone surveys)	Most commonly used for all disaster types. It is quick to mobilize and often more than adequate for initial damage and hazard identification.	World Bank, 2010
Geospatial Video and Photographic Data	LiDAR technology has been vastly improving during the last couple of years. It is particularly useful for the geospatial positioning of each measurement. It provides an accurate three-dimensional image that could be used directly for additional measurements and other special queries. It could typically be used for road and structural damage, detection of defects and obstructions.	Kwan and Ransberger, 2010
Satellite Imagery	Satellite imagery is perhaps the most accessible and easy to source through a number of providers such as Google Earth. It is powerful for the initial damage assessment of buildings and critical assets on a large scale. Obtaining images directly following a disaster event may require special arrangements.	World Bank, 2010
Aerial Imagery Collected	Aerial imagery technology has been improving significantly during the last decade with the use of drone planes becoming particularly popular. Given the high resolution of the images plus the potential combination with LiDAR information results in three dimensional images for accurate estimation for damages to buildings and critical infrastructure on a vastly large scale (See Figure 4.5 and Figure 4.6.). It can also be used to identify route blockages and further hazards on a large-scale disaster.	World Bank, 2010
Crowd Sourcing (e.g. Geo-Can)	A downside of most imaging and sometimes LiDAR information is that it relies on post processing and interpretation of images in order to translate these into useful information to a level where to satisfy planning and estimation activities. Especially for last scale disaster such as flooding and earthquakes, the extent of the processing may be astronomical. For these cases utilizing volunteers through a crowd sourcing framework may well be the most efficient course of action to turn images into the useful information. The World Bank report (2010) has assessed the effectiveness of these techniques during the aftermath of the Haitian earthquake during 2010.	World Bank, 2010
Specific Surveys (Hazard Detection)	Specific geological and other surveys are often needed following disasters to identify ongoing hazards to the community or identify areas that would no longer be suitable for inhabitance or re-establishment of infrastructure. Typical examples include areas with liquefactions, high probability of slope failures or rock falls, or areas where flooding would be an ongoing issue.	World Bank, 2010
Light Weight Survey Equipment	For road infrastructure, it is often required to undertake rapid assessment of condition, whereas the mobilization of data collection devises such as a High-speed Data survey equipment may not be possible. For such situation, a light weight Falling Weight Deflectometer and Cellphone based roughness measurement devices (e.g. Roadroid) may be appropriate.	Forslöf and Jones, 2015 and Fleming et al., 2007

Figure 4.5: Combined LiDAR and High-Resolution Aerial Imagery (World Bank, 2010)

Figure 4.6: Areal LiDAR of the Haitian Fault (World Bank, 2010)

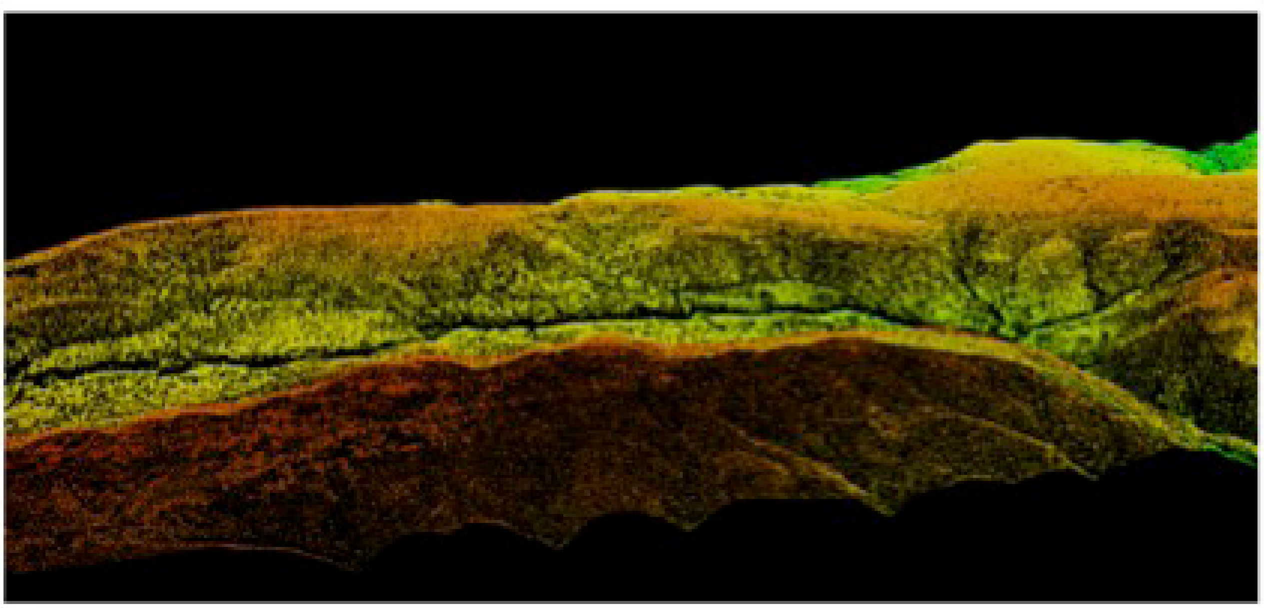
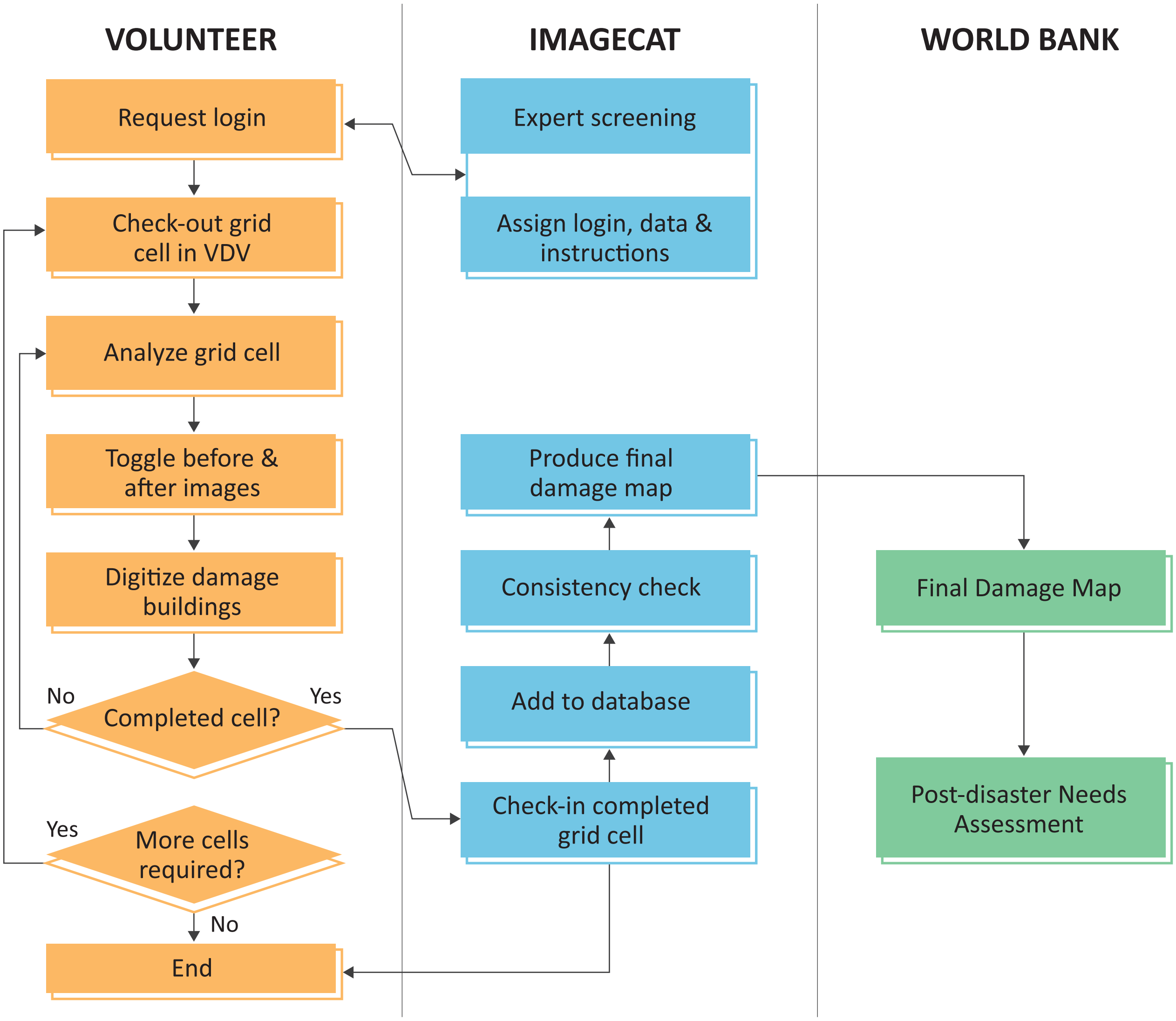


Figure 4.7: GEO-CAN Information Production Process (World Bank, 2010)



5. Understanding Risk and the Vulnerability

5.1 Risk Based Asset Management in Context

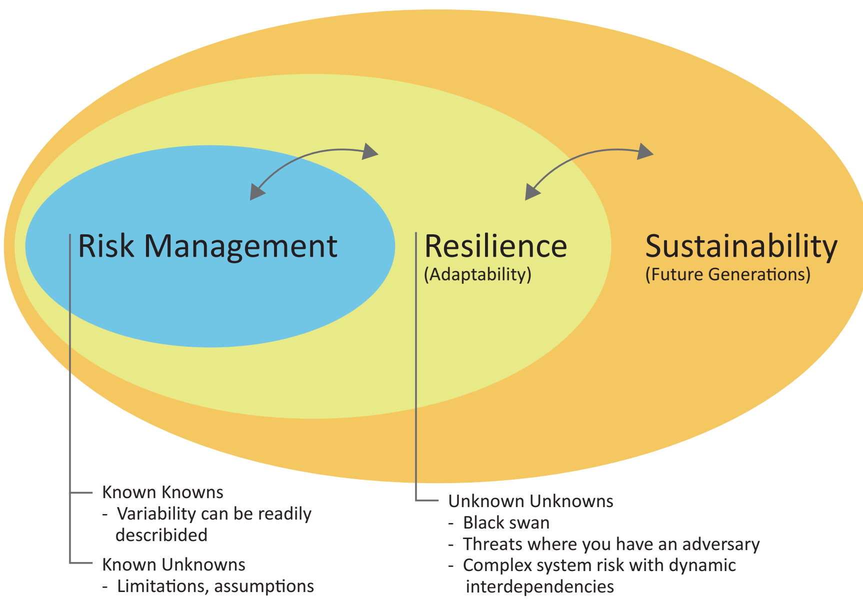
Risk analysis techniques are well-known and used as an asset management process. Especially when dealing with water infrastructure risk-based analyses processes are commonly used. Risk analyses and management is key to organisational strategic asset management. For example, the MAP-21 legislation in the USA has brought risk management to the forefront of strategic asset management (FHA, 2012). Given the nature of the questions related to climate adaptation, risk management fist naturally to the entire concept. The very nature of climate change events cannot be explained differently than considering probabilities and impacts of specific events. For that reason, risk principle has been widely used already in the risk assessment and vulnerability assessments for a number of countries such as Samoa and Mozambique.

It should be noted though that managing risk as a result of climate change is but only one risk category faced by asset managers. At an agency level, risk related to finances, strategy, hazards and operations have to be assessed holistically (Refer to Figure 5.1).

Figure 5.1: Agency Risk (FHA, 2012)

Vulnerability can also be illustrated on a continuum of eminent risks, resilience for potential future events to the long-term sustainability of a community (Refer to Figure 5.2). Asset management processes need to consider all these three from a perspective of minimizing risk, building future resilience in a sustainable manner within available and often constrained funding.

Figure 5.2 Living Standards Framework (Source NZ Treasury)



Hill et al. (2014) categorised risk management for roads into four classes of planning, management, delivery and physical risk assessment and management (Refer to Figure 5.3). The figure also shows specific risk items that can be categorised within each one of the risk classes. According to this scheme natural events and environmental risks are categorised under planning risks.

Figure 5.3: Risk Areas Used in Road Asset Management (Hill et al., 2012)

5.2 Vulnerability Assessments

The topic area of vulnerability assessments is well documented on a global scale and also on a local country levels (Diley at al., 2005, ILO, 2011, World Bank 2013). Evidence has also been found for vulnerabilities on a more local and detail level (Guzzetti, 2003, NDF, 2016). The purpose of this section is to contextualise vulnerability assessment to the asset management problem domain. The reader is encouraged to undertake further reading to learn more about the vulnerability assessments itself.

Although vulnerability assessments are undertaken for an array of reasons and applications, the essence of these assessments remain the same as illustrated in Figure 5.4. This figure also illustrates the exact asset management needs in order to plan for climate adaptions, those are:

- Having an in-depth understanding if the nature of the changing environment;
- Understanding the exact potential impact and extent of impact on the infrastructure; and
- Having an estimated time frame for changes taking place and/or the probability of disastrous events.

Figure 5.4: Vulnerability Assessments (United Nations, 2011)

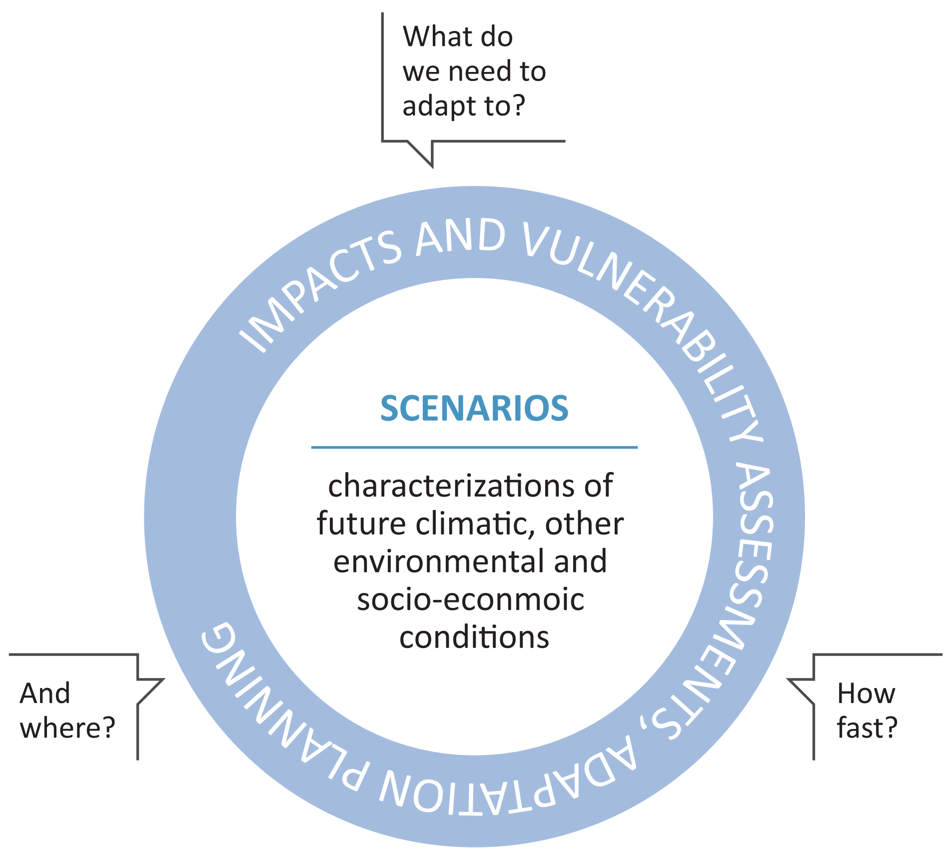
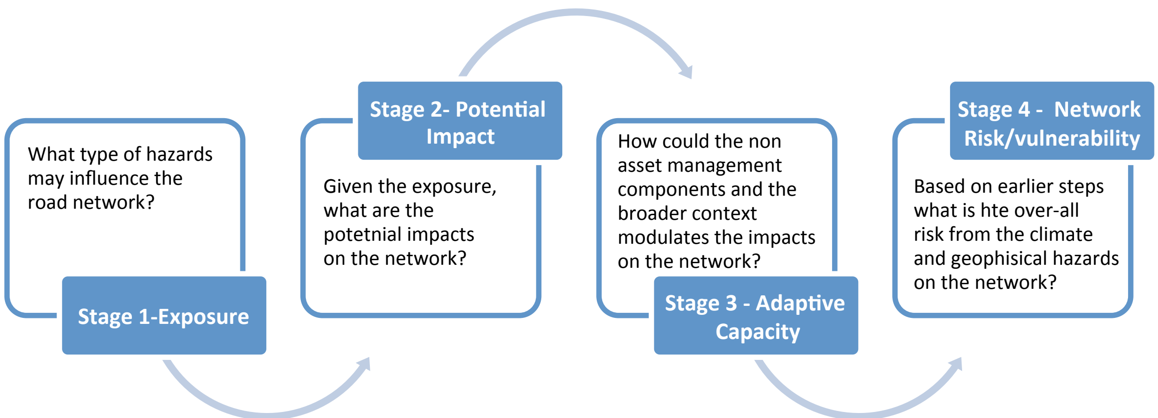


Figure 5.5 illustrate this process for the vulnerability assessment with an asset management focus. This figure has been adapted from a framework developed for a specific project. The following sections go into more detail for specific aspects related to these assessments for asset management related planning.

Figure 5.5: Process of Vulnerability Assessments (Based on Ebinger and Vandycke, 2015)



5.3 Interdependencies of Infrastructure Groups

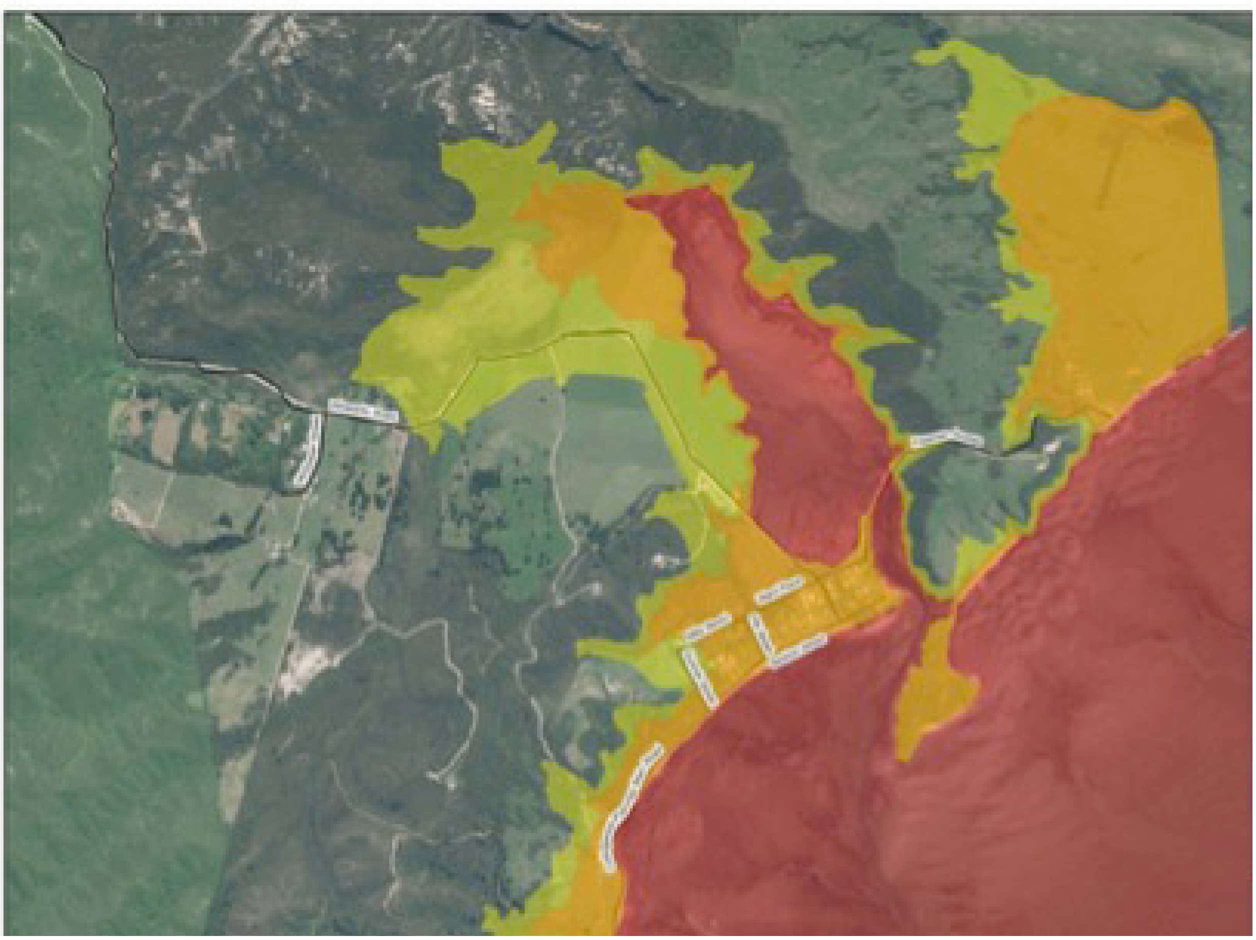
Traditional risk management and asset management processes are often asset specific centric. For example, the vulnerability of the road link may be assessed on the basis of the hazards to the road and the impact and/or consequences of the road link being out of operation is being assessed on the bases of disruption time and redundancies provided through alternative routes. Often neglected is the impact of road infrastructure on other services or asset groups. For example, a road corridor may facilitate a number of asset services in addition to the road itself. Co-location of other assets and services such as power, sewer and telecommunications may result in a road of lesser transportation importance being extremely important from a resilience perspective. Another example is roads of apparent insignificance may be access to other important locations such as water treatment plants or power stations.

5.4 Emergency Planning

Emergency planning is one of the specific outcomes from vulnerability assessments, with a strong focus on community readiness to respond during a disaster event. It takes account of the most likely hazards for a geographical area and pre-plans evacuation routes, assembly points and survival strategies in the event of disasters (see Figure 5.6). The relationship between emergency planning and road asset management is that these plans often contain critical infrastructure that is used during and directly after evacuation (life-lines). The implication is that this infrastructure (roads and /or routes) will have a significant associated criticality rating thus requiring top priority for maintaining at a high level to ensure protection at all cost against potential damage. The next section discusses the analytical processes for decision making of road maintenance. In the context of this section, a whole different set of criteria is applied when it comes to life-lines roads to ensure its absolute residence.

> *Vulnerability assessments of road networks need to take a holistic view of other assets types being dependant on specific road links.*

Figure 5.6: Evacuation Planning for Tsunami



Source: http://nelsontasmancivildefence.co.nz/tsunami-evacuation-maps/

5.5 Using Risk Management and Vulnerability Assessment in Asset Management

Section 5.1 has explained how risk management is used in asset management. This section provides some examples how vulnerability assessment and risk assessment related to climate change impacts are being applied for asset management planning processes. These examples are:

- **Protection of critical links/life lines** – Priority is given towards high risk/vulnerability road links in order to ensure these routes are able to withstand the expected storms/floods. Protection measures include sufficient provision of drainage, ensuring water-tight surface to prevent water ingress and subsequent pavement failures. Other measures may also include providing gabions on embankments and other flood protection measures;
- **Pre-empting relocation of infrastructure** – It is sometimes difficult to resettle communities prior to disasters such as storm events. Yet following an event it may be more acceptable for a community to consider a re-location. Pre-planning of such relocation will assist in earmarking of future infrastructure needs. Land acquisition and proclamation will assist in speedier post event infrastructure development.
- **Preventing over-capitalization** – When it is apparent that a road link is exposed to near certain risk of flooding or other climatic impact, it maintenance activities need to be adjusted to prevent over-capitalization that would be lost during an event. Minimum treatments and typical holding treatments could be used for such instances;
- **Identifying potential areas for resilient technologies** – Trade-off analysis could be undertaken for high vulnerability areas in order to test the cost effectiveness of resilient technologies. Note that sometime weaker and cheaper options that need more frequent replacement may be more cost effective; and,
- **Retrofitting infrastructure that is found to be significantly deficient** – Vulnerability assessment may highlight deficiencies or specific risks on some infrastructure such as bridges. A retrofitting programme could be an effective asset management strategy to reduce the potential impact form disasters.

6. Decision Making and Planning

Within the overall subject area of asset management of roads, significant research and development have been undertaken in the area of decision making. A spectrum of sophistication in decision making processes and analysis techniques was developed with the aim at making sound road investment decisions, not only for today, but also incorporating follow-on costs and returns on the investment in the long-run. These developments have resulted in decision techniques and systems that are directly applicable in assisting with some of the pertinent questions for investment into climate adaptation.

Which combination of analysis techniques is best suited to climate change adaptation may not be the same as making decisions on maintenance standards. For example, in the past life-cycle costing analysis focussed on the agencies own direct costs has been central to road asset management investment decisions for many road agencies, whereas climate adaptation requires a much wider approach in determining the best return on investment – especially when the benefits of taking some decisions may reside in services entirely outside the road sector (e.g. maintaining a minor road in operational condition because it has a water main beneath it).

Other factors such as community well-being, socio-economic factors and cultural considerations now has to be part of a decision process that is very much focusing on future risks of climatic impacts. Where historical analysis and modelling techniques had to understand variability in data, modelling climate adaptation also brings a much greater emphasis on modelling uncertainty in predictions.

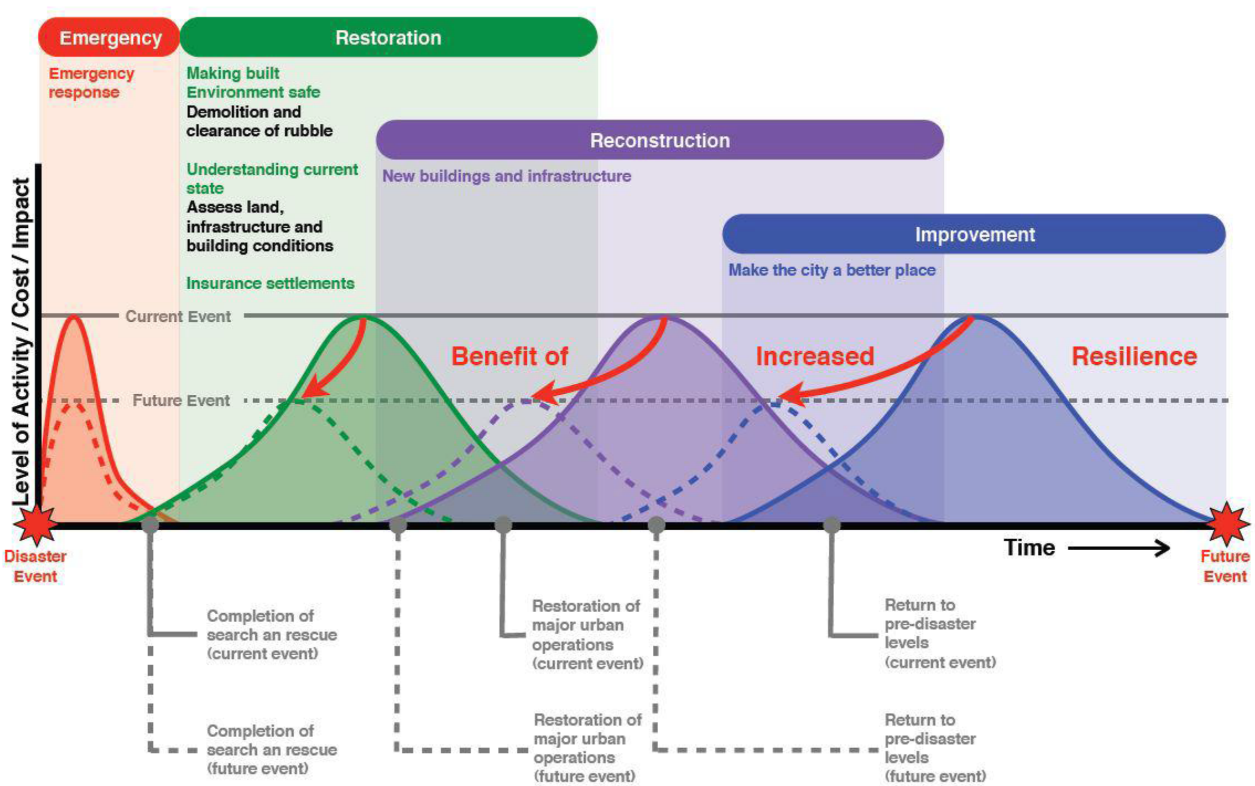
This section details some specific considerations of road asset management decision making processes and how it relates to decisions for incorporating climate adaptation. This section also summarises some of the most appropriate decision making analysis techniques that could be used in this area.

6.1 Resilience Planning

6.1.1 Importance of Resilience Planning

The importance of resilience planning is effectively illustrated in Figure 6.1. This figure attempts to illustrate the benefits of building in more resilience into the infrastructure during the rebuilding of Christchurch following the 2012 earthquakes. It shows that savings from resilience would be experienced in all the phases of a shock event, including the emergency response, restoration, reconstruction and improvements.

Figure 6.1: Benefit of Increasing Resilience (Fairclough, 2013)



Resilience is not only a consideration following a shock event; it should be a priority before any event. Asset management strategies have to be developed more proactively by focusing on network planning and vulnerability assessment, developing the right technical specifications and materials and robust environmental impact assessment rather than by focusing on the more reactionary aspects of emergency response and rescue.

6.1.2 Resilience Planning Defined

Resilience planning focuses on the climate adaptation of infrastructure to better deal with both slow-changing climatic impacts and being better prepared for the shock events. The over-all resilience planning process is summarised in Figure 6.2, while some typical questions and analyses expected in this area are summarised in Table 6.1.

> *The climate change events provide an opportunity to learn from and build back better but the primary objective of climate resilient asset management should be to enhance the resiliency of road infrastructure and minimize the climate change impacts.*

Figure 6.2: Resilience Planning Process (Ebinger and Vandycke, 2015)

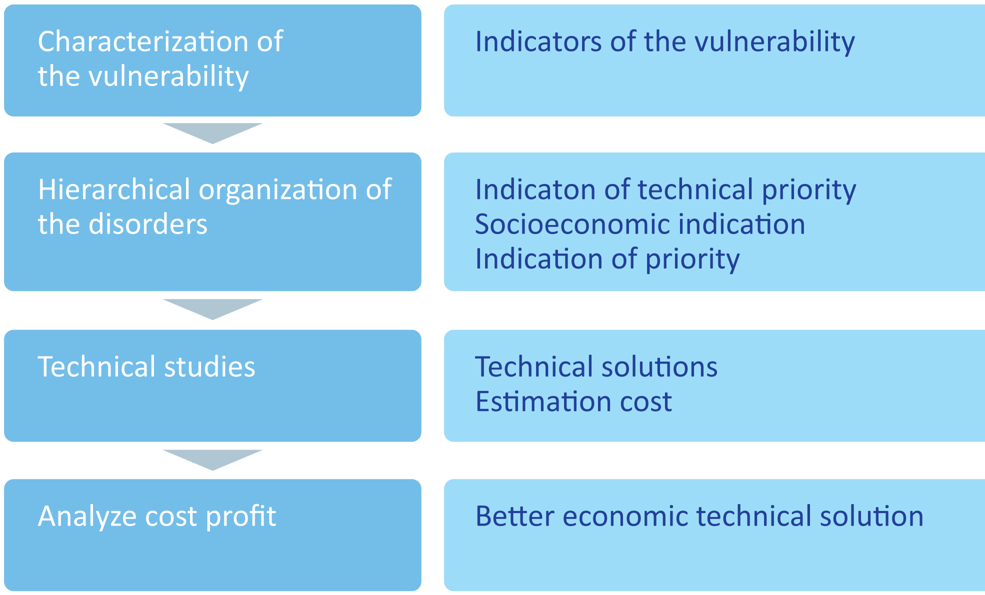


Table 6.1: Analysis Questions for Resilience Planning

Management Question	Analysis Approach	Specific Techniques	Additional information or development needs
What are the climate impacts on the deterioration of the road network?	Using mechanistic design methods and/or pavement deterioration models to establish a relative performance and cost differential to performance under normal climatic conditions	Life-cycle costing (LCC)	Better understanding of the specific performance of road materials under varying climatic conditions
What are the best road maintenance scenarios to minimize failure risks?	Risk based analyses	LCC and Risk	The ability to quantify the risk reduction realized from different maintenance strategies
Option analyses for more resilient technologies? (1)	Classic and adjusted long-term benefit/cost analyses	LCC and others	Better understanding of the long-term performance benefits of resilient options. The same applies for the performance of resilient technologies during shock events
Relocation of specific vulnerable road links?	Socio-economic impact analysis	LCC, Multi Criteria and Multi-objective analysis	Quantifying socio-economic benefits for different road location/route options

Note: (1) More resilient technologies may well not be the most cost effective option. Bigger, better and stronger may be more expensive than deliberately adopting an opposite strategy of providing weaker solutions that cost less to be replaced more frequently.

A case study on a specific route in Samoa investigated three resilience options:

- Rebuild to existing standards;
- Rebuild to improve residence; and,
- Relocate to higher ground.

The aim of this case study was to compare the outcome in following an engineering economic assessment process to a socio-cultural assessment process. The engineering/economic assessment considered:

- Initial capital investment;
- Long-term maintenance; and,
- Risk cost for repeating storm damage.

The socio-cultural assessment used the Mauri[2] model that was developed in New Zealand, and has been successfully applied in the Pacific context (Morgan, 2009). Table 6.2 lists the Indicators used for the assessment.

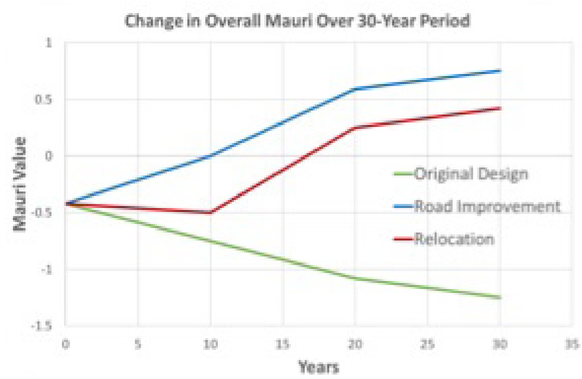
Table 6.2: Indicators Used in the Mauri Model (Brown and Ott, 2016)

Dimension	Indicator
Environmental	• Water Quality • Resources used • Amount of land used
Cultural	• Kaitiakitanga(2) • Heritage protection measures • Traditional Customs
Social	• Public Health and Safety • Amount of land used • Inconvenience to affected community
Economic	• Implementation Cost • Maintenance cost • Profit

[2] Mauri – Maori word for "the essential quality and vitality of a being or entity"
Note: (2) Practice of spiritual and physical guardianship of the environment

The main finding of this case study suggested that a pure engineering/economic assessment does not always provide the ideal option analyses required for climate adaptation questions; a more holistic assessment is often required. Figure 6.3 shows the outcome of the case study. The economic assessment favours the relocation options, whereas the Mauri assessment significantly favours the road improvement option.

Figure 6.3: Case Study Findings of Addressing a Flood Damaged Road in Samoa (Brown and Ott, 2016)



6.2 Risk Based Option Analyses

Two risk-based decision tools were assessed as part of this project. A brief description of both these tools are followed by a comparative functionality assessment **(Refer to Error! Reference source not found.).**

ROADAPT (Deltares, et al, 2015) was developed on a grant from the Conference of European Director of Roads (CEDR) Call 2012 'Road owners adapting to climate change'. It was largely based on the 2010 development of "Risk Management for Roads in a Changing Climate".

> ***ROADAPT** aims at providing methodologies and tools enabling tailored and consistent climate data information, a good communication between climate researchers and road authorities, a preliminary and fast quick scan for estimating the climate change related risks for roads, a vulnerability assessment, a socioeconomic impact analysis and an action plan for adaptation with specific input from possible adaptation techniques related to geotechnics and drainage, pavements and traffic management. (Quoted from Deltares, et al, 2015)*

Valuing Resilience in Infrastructure (Cornish et al., 2017) A research project for the New Zealand Transport Agency developed an updatable 'decision support tool' to consistently weigh up different controls to create an acceptable level of resilience in (transport) infrastructure with priority given to desired community outcomes. The tool has many strengths:

- It follows a business case process of deciding on the most appropriate option to address a current vulnerability;
- There is an existing data structure that underpins the tool – for most cases, the existing data can be used and only specific regional data such as climatic records and unit cost for treatment need to be updated;
- It covers a multi-asset and multi-hazard approach;
- It is able to capture organizational knowledge into a permanent record.

Note the tool will be officially launched and made available during early 2017.

6.3 Post Event Planning Considerations

Although the specific road/route functions may change over time, the road infrastructure remains one of the top critical infrastructures during the entire duration and in the direct aftermath of the disaster. Table 6.3 lists some of the priorities following an event along with the specific road network function for each one of the priorities. Although access is in most cases the main function for the road network, being able to carry sufficient capacity (e.g. during evacuations) could also be important.

Table 6.3: Immediate Priorities Following a Disaster (based on Ferreira et al., 2010)

Priority	Objective	Priority	Road Network Function
High	Support Immediate Rescue	33 %	access & capacity
	Enable Support from other Areas	17 %	access
Medium	Support Lifelines	15 %	access
	Repair Key Infrastructure	14 %	wider mobility
Low	Facilitate Accessibility Between Communities	7 %	connectivity, access and capacity
	Protect Environment	6 %	
	Protect Private Property	4 %	
	Protect Economy	4 %	

For obvious reasons decision making following a disaster event is unique. Although it is believed that asset management processes could be of great value during these planning stages, there are some considerations that should be kept in mind that include:

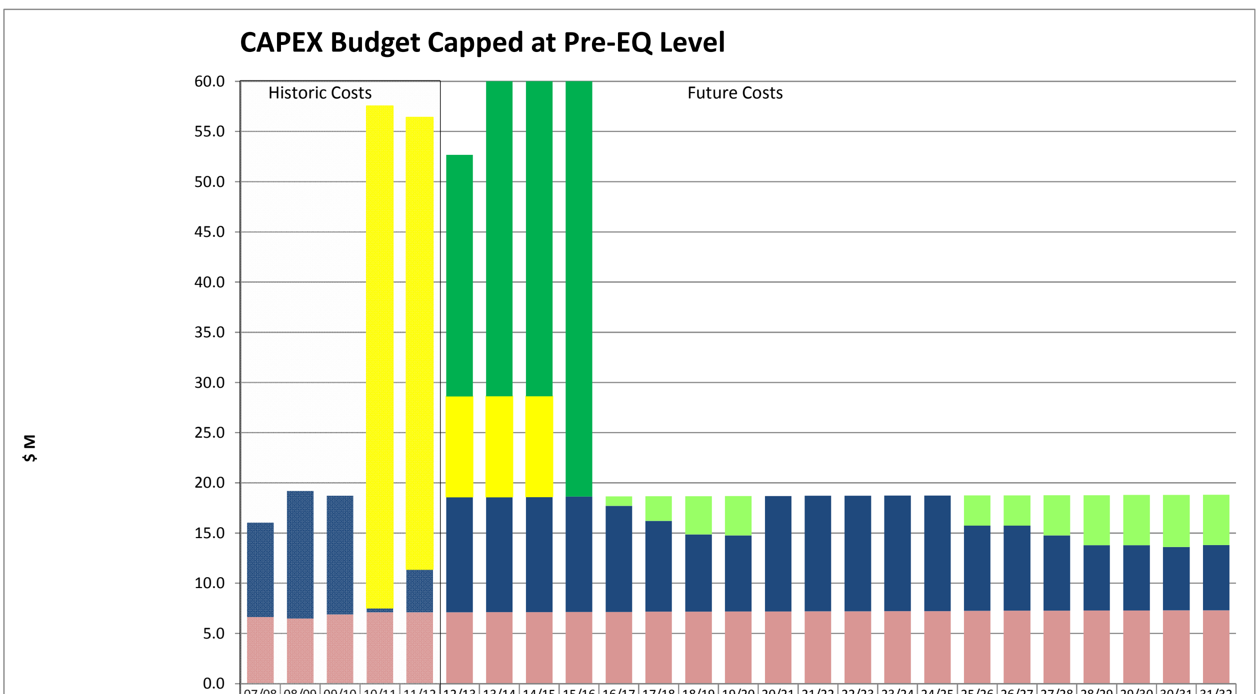
- **Planning stages** (response, recovery, and rebuilt) are distinct stages following a disaster. Each one of these stages may include a full asset management cycle, although the planning time horizon of the stages are different:
  - Response – planning for the next hours and days;
  - Recovery – planning for weeks and months; and,
  - Rebuild – planning for the long-term, even longer than normal asset management cycles. For example, if planning a new city lay-out it may be taking account the needs of the next generation.
- Overwhelming feeling of ***"where do we start?"*** Many post disaster reviews of major events often document the initial stages of the planning processes to be un-organised and fragmented. Having pre-event planning strategies in place assists bridging this stage quickly. Some of the pre-event planning strategies may include:
  - Where will the data be sourced from;
  - How to mobilise planning work forces;
  - Where is the most likely places where the planning will take place;
  - How will the planning processes be managed (See Section 1.1)?
- **Nature of the disaster.** Obviously, the nature and specific damage following a disaster will determine the planning needs. Note some disasters may have a long period of follow-on effects;
- **Interconnectedness of infrastructure.** During recovery and rebuild planning the Interconnectedness of infrastructure is a major driver during the planning process. For example, during the Christchurch rebuild, the replacement of sewer lines was the leading scheduled items during the rebuild – occurring prior to the rehabilitation of the road. This often meant that relatively easy to repair roads were deferred until other assets were repaired;
- **Mobilisation of workforce** – The ability to get workforces mobilised is a significant challenge after major events as workers will also have their own families and properties o attend to, which can also drive the planning schedules (See Section 1.1)
- **Community involvement in decision making.** Most disasters are often associated with significant tragic circumstances of loss of life, destroyed properties and the displacement of large numbers of people. The human and psychological element of the recovery process should be on the forefront of priorities. Getting community involvement in the decision making and actual rebuilding is vital also for the mental recovery that needs to take place. This priority does bring a specific need to the planning process, how it is done and how it is communicated;
- **Build back better** is a concept of ensuring the best outcome for the community when decisions are being made and often financial aspects becomes only one of the considerations. One of the main considerations during this stage is the balance between cost and future proofing;
- Rebuild **centralised versus decentralised**. One of the main resilience measures of infrastructure is to decentralise thereby creating redundancy in the system. Although road assets are less affected by this consideration when compared to other asset types, the outcome of these decisions may impact on road lay-out and specific design.

6.4 Analyses Techniques

Literature on the topic area of post disaster decision making mostly deals with incorporating community involvement into the decision-making process (Binder et al., 2015). Less literature exists on advanced decision-making techniques, in particular for the rebuilding investment planning process. By incorporating existing asset management analytics, useful decision making information could contribute towards more effective outcomes being achieved more efficiently. For example, during the rebuilding of Christchurch, predictive modelling software normally used for long-term maintenance investment decision making was effectively used for the investment planning of the road network reconstruction (Rainsford, 2012). An outstanding characteristic of this analysis was the trade-offs between cheaper "holding actions" with more expensive rehabilitation treatments.

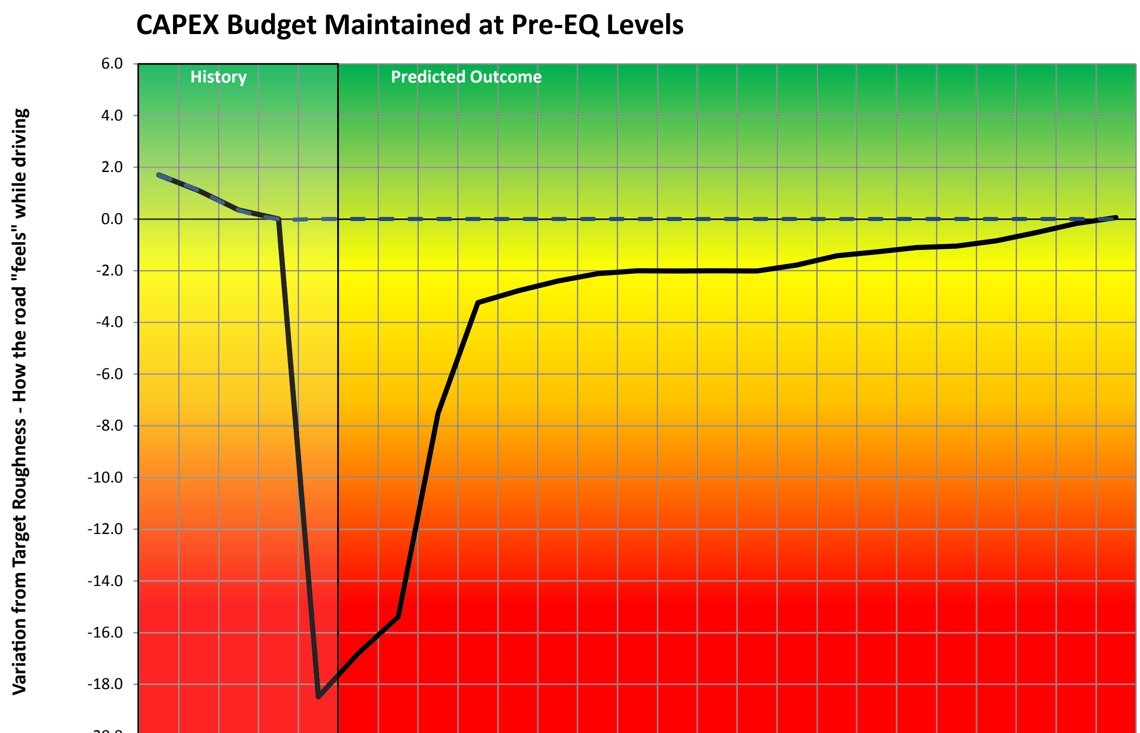
Figure 6.4 and Figure 6.5 show two typical examples of modelling outcomes produced for the reconstruction of the Christchurch road network. The figures show both the forecasted investment needs and the predicted condition outcome as a result of this investment. Note that by law, the New Zealand government could only commit six years of funding towards the rebuilding process, hence the six-year spike in financial investment. Furthermore, there is a clear change in the works programme focusing initially on access and "make-safe" repairs to later treatments that were more permanent in nature.

Figure 6.4: Forecasted Rehabilitation Costs of Christchurch Road Network Rebuilt (Sean Rainsford, 2012)



	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31	31/32
Est. SCIRT Road Rebuild Costs						24	52	83	94																
Est. CCC AMP SCIRT Related Costs										0.9	2.5	3.8	3.9	0.0	0.0	0.0	0.0	0.0	3.0	3.0	4.0	5.0	5.0	5.2	5.0
EQ Make Safe Repairs				50	45	10	10	10																	
CAPEX Budget Level	9.4	12.7	11.8	0.4	4.3	11.5	11.5	11.5	11.5	10.6	9.0	7.7	7.6	11.5	11.5	11.5	11.5	11.5	8.5	8.5	7.5	6.5	6.5	6.3	6.5
OPEX Budget (predicted)	6.6	6.5	6.9	7.1	7.1	7.1	7.1	7.1	7.1	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.3	7.3	7.3	7.3	7.3	7.3	7.3

Figure 6.5: Forecasted Performance from the Modelling of Christchurch Road Network Rebuilt (Sean Rainsford, 2012)



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Roughness	1.7	1.1	0.3	0.0	-18.5	-16.8	-15.4	-7.5	-3.2	-2.8	-2.4	-2.1	-2.0	-2.0	-2.0	-2.0	-1.8	-1.4	-1.3	-1.1	-1.1	-0.8	-0.5	-0.2	0.1
Roughness Target - Pre-EQ	1.7	1.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

A summary of most commonly used post disaster analysis techniques is listed in Table 6.4.

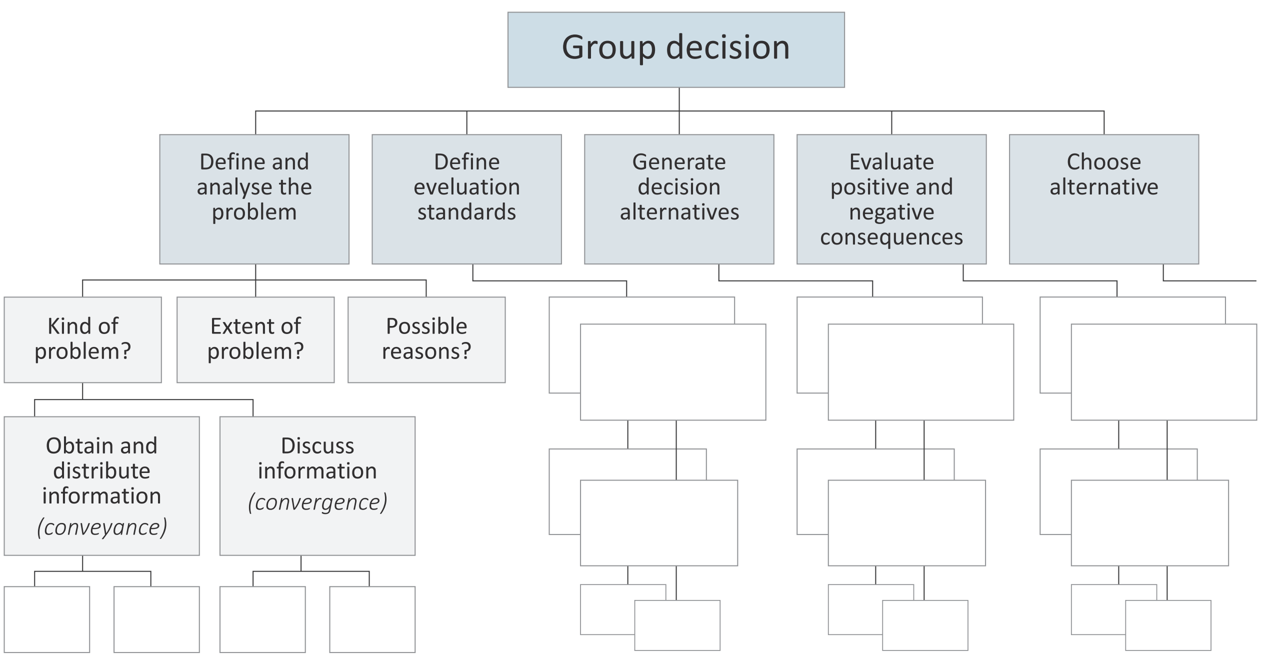
Table 6.4: Most Commonly used Analyses techniques for Post Disaster Decision Making

Technique	Description	Notes
Delphi decision making	A panel of experts are used to make decision, mostly on the priority of investment areas. Each panel member presents their results to the group, following by the group reprioritising their original priorities following the discussions. The ultimate solution is delivered when the panel priorities converge.	This is an effective decision making process for the initial and principle decisions related to rebuilding. More detail analyses need to supplement his technique.
Hierarchical and Sequential Structure of Group Decision-Making	This process is similar to the Delphi process with the difference in structuring the decisions into specific groupings and hierarchies (See Figure 6.6).	Very popular for the initial decision stages following an event. More detailed analyses need to supplement his technique.

Technique	Description	Notes
Multi-criteria analysis	Multi criteria analysis compliments the above-mentioned techniques and is particularly used to consider different criteria for option analysis.	This is an effective technique for considering multiple criteria to rank preferences on various options. Downsides to the technique is that it is subjective and doesn't always have a long-term perspective to decisions.
Traditional Road Management Systems	Road maintenance planning techniques that is used for the forward works planning of road maintenance and renewal programmes. Some of these tools include forecasting capabilities and optimisation routines that allows for long-term prediction of different investment scenarios that optimises the return on investment.	Ideal for long-term road investment planning that could also include post disaster rehabilitation and reconstruction work. It allows for trade-offs such as holding actions versus reconstruction treatment. A common limitation to these techniques is that it only considers single objective functions for the optimisation. In most cases the objective function would be to maximise agency and road user cost for given investment scenarios.
Multi-objective Optimisation	Multi-objective optimisation techniques are able to consider multiple quantitative and qualitative criteria to maximise the return on an investment on an array of considerations. (Chen et al., 2015)	This technique is able to maximising return on investment from financial, risk and customer expectations perspective. The techniques are not commonly used and outputs are sometime complex to interpret.

The chosen technique will largely depend on the situation following the disaster, such as the availability of data and specific objectives of the planning process.

Figure 6.6: Hierarchical and Sequential Structure of Group Decision-Making (Kolbe and Boos, 2009)



6.5 Assessing the Benefits of Climate Adaption Techniques

There is already significant literature documenting climate adaptation measures for roads. These vary from identified resilient technologies to other more general climate change mitigation measures. The World Bank has recently released a report on the use of "Green Construction Material" in India (The World Bank, 2016). The report particularly considered the use of by-product material as alternative construction material. Some examples include (World Bank, 2016):

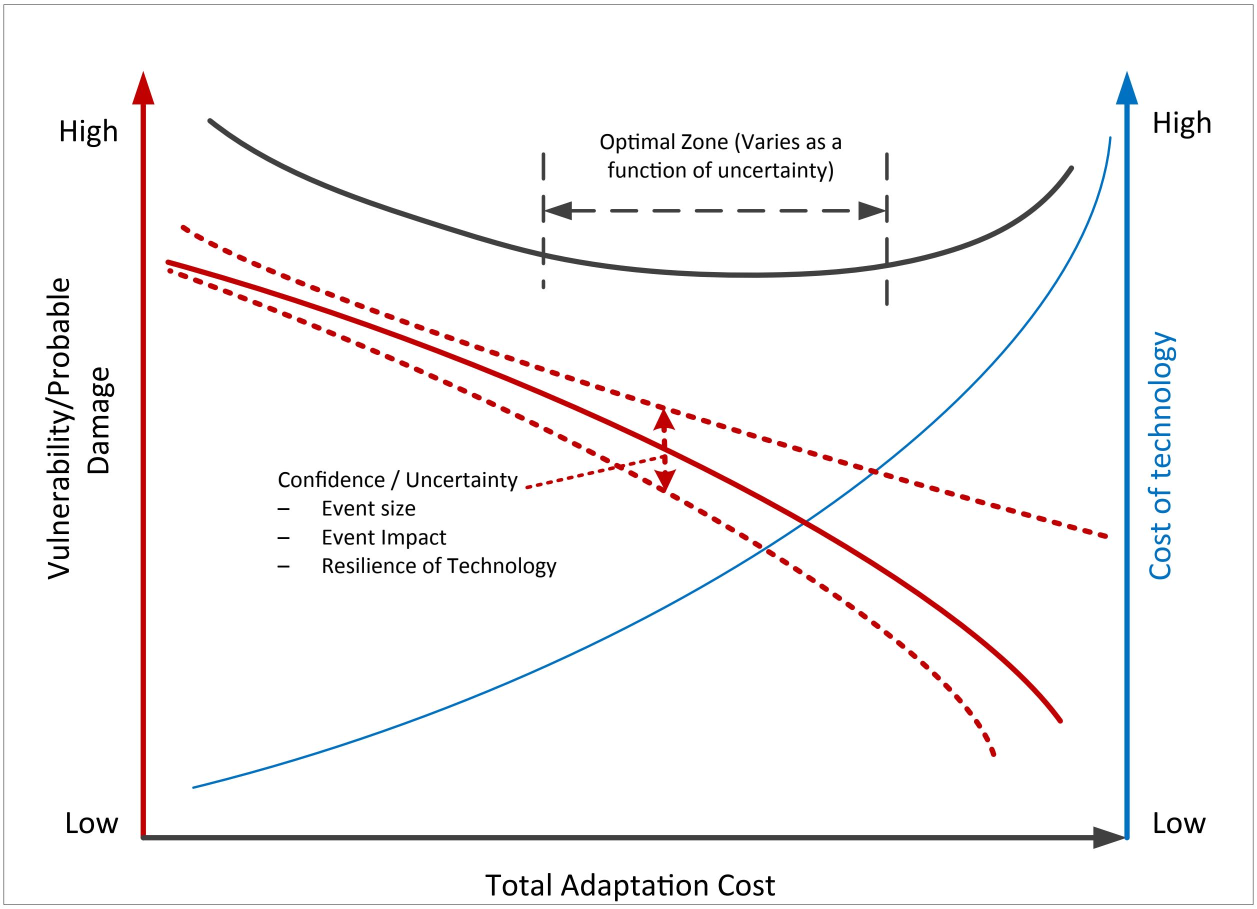
- Reclaimed bituminous material (RA);
- Crushed concrete;
- Pulverized fuel ash (PFA or fly ash);
- Blast-furnace slag;
- Steel slag;
- Other metallurgical slags (e.g. chrome, manganese, copper, zinc);
- Aluminum industry wastes;
- Colliery spoil;
- Construction and demolition waste
- Mine and stone processing waste (marble, slate, granite, etc.);
- Phosphogypsum;
- Used tires;
- China clay sand;
- Foundry sand;
- Crushed waste brick;
- Used rail ballast;
- Furnace bottom ash;
- Cement kiln dust;
- Glass;
- Spent oil shale.

A common trend that resulted from this work was the lack of information to the construction standards and the performance expectations from these materials.

Another related aspect is to have a more sustainable approach to the design and construction of roads. Given that climate adaptation fall within the sustainability concept, such a more holistic process is advisable for adoption on a global scale. A good example for minimising environmental impacts form road is presented in Quitero (2015). This document presents a strong methods of impact assessment and some suggestion to mitigate the impacts.

A key success factor in analysing different options for road programmes with the aim of integrating climate adaptation is the ability to assess the long-term outcomes from these options. There is significant uncertainty of the specific impact of climate change on road networks, which is further aggravated by uncertainty of the long-term outcomes from adaptive technologies and strategies (refer to Figure 6.7).

Figure 6.7: Trade-off between Cost and Return of Resilience Technology



> *In order to warrant the use of resilient technologies, we have to know what value it returns in relation to reducing the vulnerability of the asset. This area is perhaps the area of greatest need for research and development.*

6.6 Monitor the Progress towards Resilience

A major part of asset management – particularly in the planning cycle of asset management – is the measurement and monitoring of performance in relation to defined standards and/or past performance. Planning into the future is underpinned by the knowledge of the historical performance up to the current situation. Performance monitoring and measurement consist of the following processes (Henning, Costello and Tapper, 2013):

- A report on the status of the current performance;
- Trend monitoring that tracks the past performance in relation to the factors that may have impacted on the performance (such as investment levels); and,
- Benchmarking – where an agency compares a matrix of performance measures against other agencies.

A literature scan has revealed substantial work that has been completed in the topic area of quantifying resilience for communities, regions and countries. The process varies significantly from theoretical processes to more simplistic measurement and reporting of key measures that define the resilience. The following paragraphs provide two examples of such frameworks.

During a study for the U.S National Science Foundation, a measurement framework was developed to assess resilience of a coastal community along the Northern coastline of Mexico. A theoretical model was developed that calculates the resilience inference. It uses three elements (exposure, damage, and recovery indicators) to denote two relationships: vulnerability and, adaptability (Refer to Figure 6.8). The next resilience cycle consists of adaptation (minimising the future damage) and mitigation (minimising the exposure).

Figure 6.8: Resilience Framework (Lam et al., 2016)

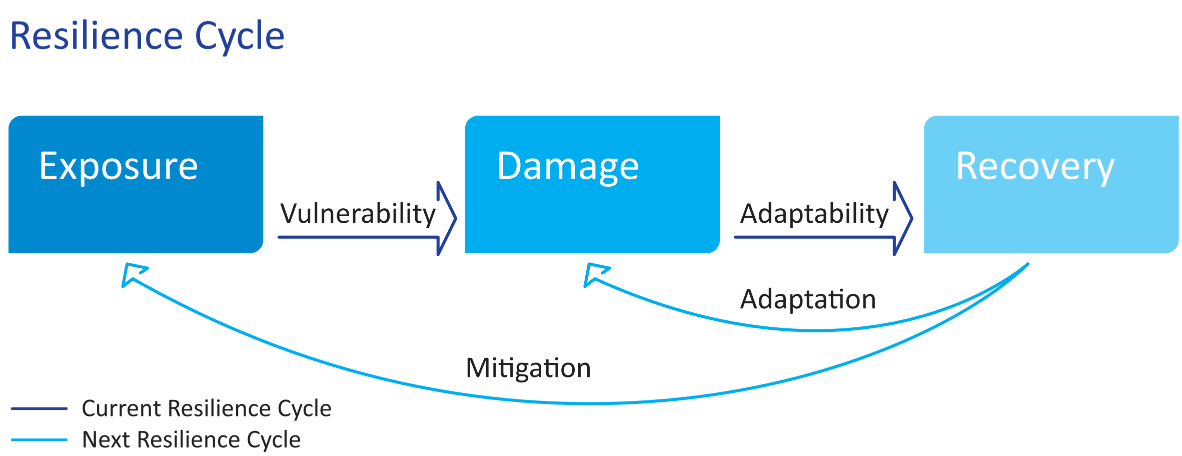
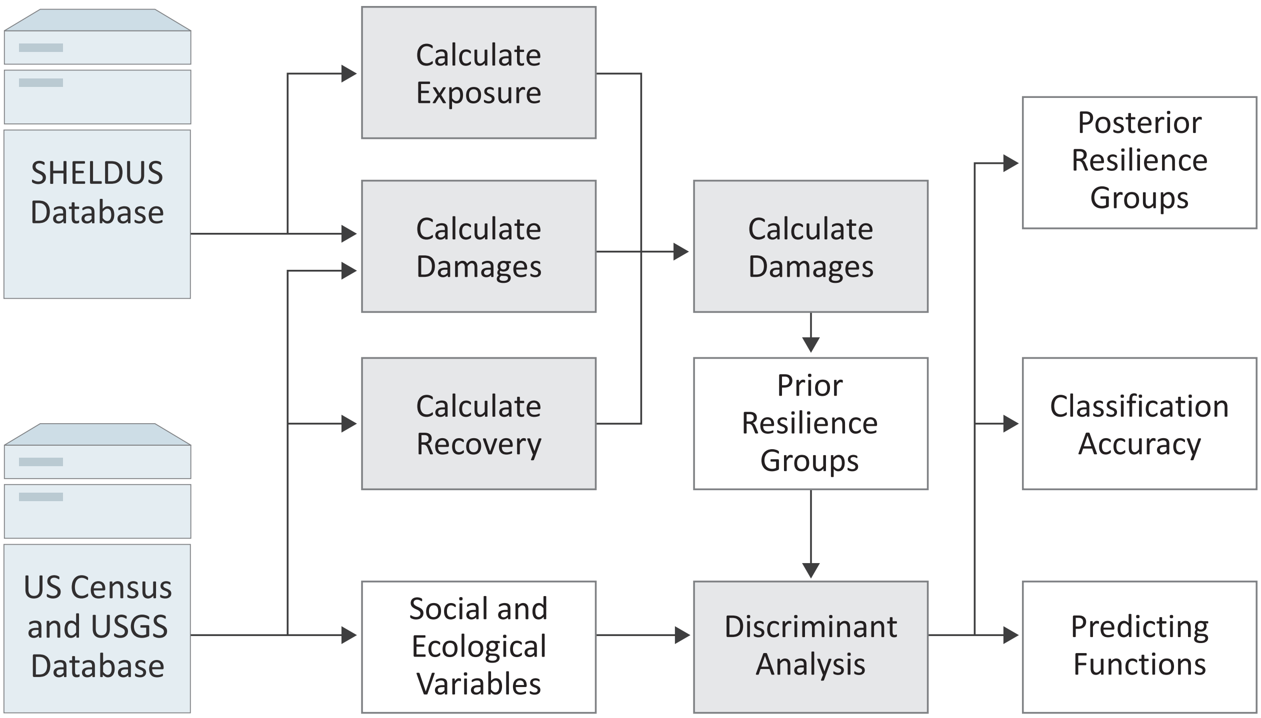


Figure 6.9 illustrates the process of calculating the coastal resilience. The input data for the model was obtained from two sources:

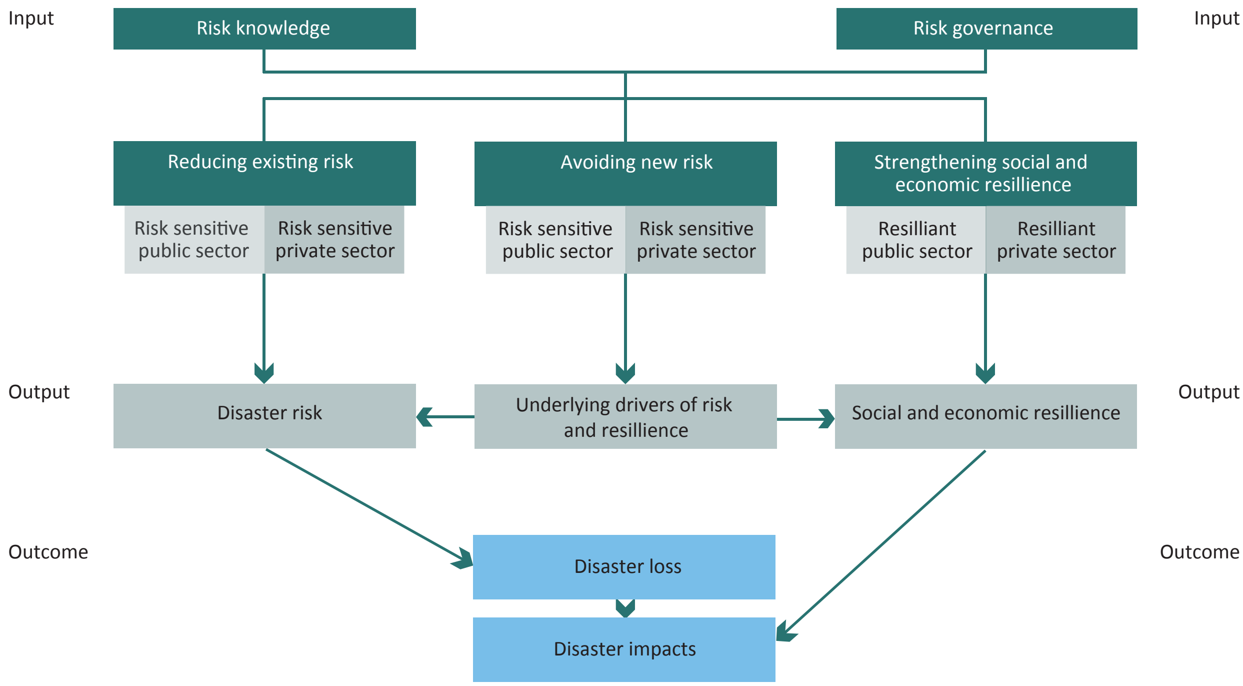
- Spatial Hazard Events and Losses Database for the United States (SHELDUS); and,
- National Oceanographic and Atmospheric Administration's (NOAA) National Climate Data Centre (NCDC), which provided the exposure and damage data for the coastal counties.

Figure 6.9 Process of Calculating Coast Resilience (Lam et al., 2016)



The UK Overseas Development Institute has developed a measurement framework for measuring disaster risk reduction on a global scale (Refer to Figure 6.10). The output element that could be monitored includes: disaster risk, and social and economic resilience. Ultimately, the outcome measures would include disaster loss and disaster impacts.

Figure 6.10: Proposed Performance Monitoring Framework for Disaster Risk Reduction (Mitchell et al., 2014).



From this report, a number of valuable recommendations were proposed (Mitchell et al., 2014):

- *"A target set on Disaster Risk Reduction (DRR) should combine the targets with a methodology that assesses levels of disaster risk. Only then can we adequately track progress in reducing disaster risk;*
- *Indicators could monitor inputs and outputs, such as presence of plans or legislation, number of people covered by effective early warning systems and/or school and health facilities built to hazard-resistant building codes, linked to the hazard risk in the area.*
- *It is important to establish clear, numerical targets at a global scale to act as eye-catching, awareness-raising;*
- *A disasters data revolution is needed, involving the systematic collection of data on disaster risk and disaster losses across countries to enable the establishment of national and global trends;*
- *A monitoring methodology for tracking national progress on DRR must focus on the use of detailed disaster risk information, including high-resolution data on national building inventories, population data (including by socioeconomic group), mapped hazard data and DRR plans;*
- *Upgrades to poverty data should involve modules on shocks. Where countries start more comprehensive, regular monitoring of poverty dynamics, potentially by extending household surveys, such poverty surveys or other data collection methods should incorporate modules or questions about the impact of disaster events on income poverty and other dimensions of human development, such as health or school attendance;*

- *Tracking progress on disaster losses and risks requires data to be normalised for key variables, like population or GDP, to allow for comparisons between time periods. It also requires the establishment of a baseline against which progress can be assessed.*
- *The institutional architecture for delivering a global monitoring system needs to involve multiple groups at different scales, each serving a distinct function; and,*
- *While governments will continue to self-report progress, it is vital that independent groups at all levels can contribute to the overall framework for monitoring progress on DRR."*

The latter approach is perhaps the most relevant and appropriate for monitoring resilience in the developing countries. It is recommended to develop a resilience framework specifically aimed to monitor the resilience of countries and regions on the bases of the Bank's investment agendas and development objectives.

7. Conclusions

7.1 Main Findings

This report considers the integration of climate adaption to existing asset management processes and techniques. The specific objectives were to:

- Review the entire asset management process in the context of how climate adaptation measures could be incorporated;
- Explore specific techniques related to data collection and decision making that fits within the problem domain of climate adaptation; and,
- Identify the future development issues that will assist more seaming less integration of climate adaptation into asset management processes.

The main conclusion of this report is that asset management, when undertaken according to best practice, is already one of the most significant climate adaptation strategies. There are many processes and techniques that are used to develop optimal maintenance and renewals programmes that result in more resilient road networks. However, so much more could be done in order to effectively integrate climate adaptation into business-as-usual asset management.

Better data and information assist in better decision making. Investing into the collection of relevant data and information is the first and foremost investment into climate adaptation. With minor adaption to existing asset management processes (refer to Figure 7.1) and techniques, a far greater return may be gained from investment to allow for changing demands on road infrastructure, both from a changing climate and from an ever-changing population.

> *Climate change is real and it will cost road agencies money. Doing something about the changes proactively will not only mitigate the financial impacts but also result in more resilient communities.*

Figure 7.1: Asset Management Process (NAMS. 2011)

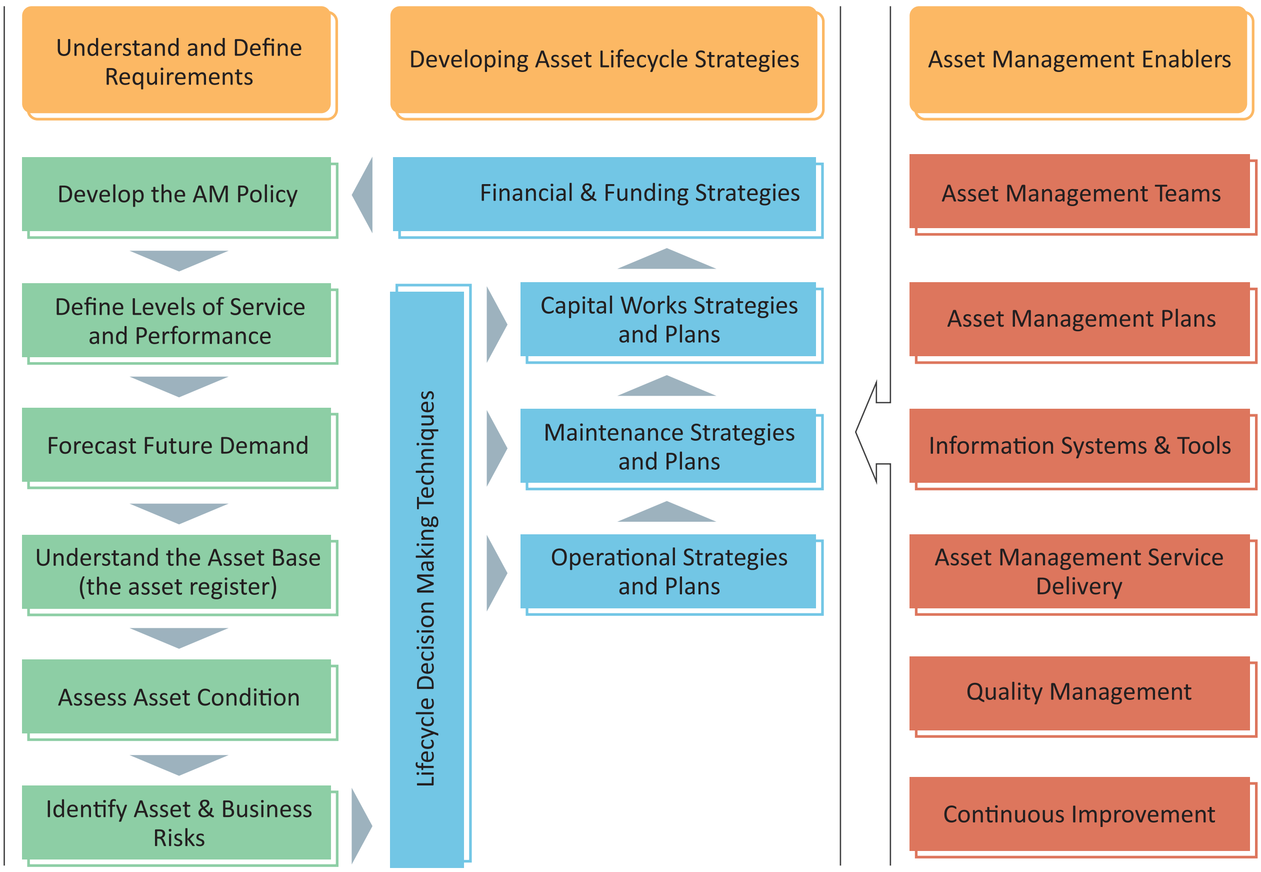


Table 7.1: Summary of Key Actions to Implement Climate Change into Asset Management

	Step	Key Additional Actions
Understand and Define Requirements	Develop the AM Policy	• Specifically address climate change within the AM Policy statement, including what horizon is to be planned for • Have agreements in place on how the damage from major events will be funded and who will be entitled to financial support
	Define levels of service and performance	• Ensure network resilience measures (e.g. restore all major roads within 12 hours of end of 1:100year flood) are included into the level of service framework • Revise design guides to take into account the changing frequency of climatic events
	Forecast future demand	• Future demand forecast such as demographical changes and traffic loading increases should be integrated with climate change impacts on the expected performance of infrastructure • Providing for future growth in areas of high vulnerability should be avoided

	Step	Key Additional Actions
Understand and Define Requirements	Understand the asset base	• Ensure that data on drainage assets and their vulnerabilities/deficiencies is complete and up-to-date • All data collection processes should be geospatially referenced • Road data and information should highlight interdependencies with other infrastructure • Link life-lines and critical interactions between asset groups in the base data
	Assess asset condition	• Data collection should include measuring and recording of specific climatic effects on road network • Data collection techniques should also include the focus on quantifying the vulnerabilities of pavements to temperature and moisture changes
	Identify asset and business risks	• Ensure climate change is recognised as a risk to the asset and delivery of services • Risk and vulnerability assessments are already commonly used for climate adaptation. These processes should be integrated with risk management from an organisational risk perspective • The integration with asset management risk in particular promises significant efficiency gains
Developing asset lifecycle strategies	Lifecycle decision making techniques	• Road asset management and systems brings a wealth of analytics to the climate adaptation topic area • Current analyses processes need to incorporate multi objective capabilities • More emphasis on community involvement in decision making is required when bringing climate adaption into the asset management decision making
	Operational strategies and plans	• Operational plans should include specific allowance for identifying and addressing deficient adaptation measures – such as making sure drainage structure are cleaned and without blockages • Include retrofitting infrastructure that is found to be significantly deficient • Trial new materials that may better resist climate change • Operational procedures should include policies and processes identified for responding to disasters
	Maintenance strategies and plans	• Maintenance strategies and plans should include specific allowance and focus on addressing items that limit the impact from climate change
	Capital works strategies and plans	• Updating of current design criteria (such as drainage design) is needed to allow for changing rainfall patterns • New designs should include specific consideration for climate adaptation technologies
	Financial and funding strategies	• Financial and funding strategies should investigate the impacts of different investment scenarios into climate adaptation • Financial and funding strategies should be in place for responding to potential disaster events

	Step	Key Additional Actions
Asset management enablers	Asset management team	• Effective integration of climate adaptation and asset management must be driven from executive management levels within organisations • Appoint someone as the climate change champion to drive all these actions through the organisation
	Asset management plans	• Ensure that the AMP specifically addresses climate change
	Information management systems and tools	• Information management systems should be including the recoding of specific climatic and impact data for planning purposes • A data residence plan should be in place to respond to disaster planning needs
	Asset management service delivery/ Procurement	• Legislation and procurement processes should allow for the response to shock events
	Quality management	• Quality management of climate adaptation measures need to ensure its sufficient functioning
	Continuous improvement	• Identification of improvements necessary for climate change adaptation

7.2 Further Work

One of the findings of this report suggests that the integration of climate adaptation into asset management is not an onerous and significant process. Many existing processes and techniques are directly applicable to consider climate adaptation. However, considerable commitment and leadership is required to facilitate and incentivise such integration. Therefore, there is a significant responsibility of road agencies and funding bodies to push for drastic changes that will allow for this integration. The reality is that the do-nothing option in this regard is simply unaffordable.

This report also highlighted some challenges to the research and academic fraternity in understanding climatic impacts on road networks better, developing more resilient technologies and, most importantly, developing a better understanding to quantify the impact/benefits of climate adaptation strategies.

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