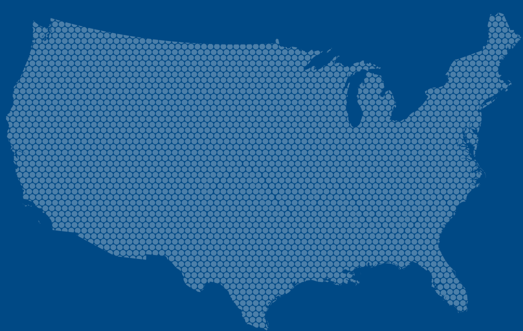
FEHRL US SCANNING TOUR 2012
CLIMATE ADAPTATION FOR ROADS



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1 INTRODUCTION

A significant global challenge facing decision-makers involves the identification and assessment of the effects of climate change in relation to transport. Research suggests that considerable changes in climate have been emerging and are expected to become more pronounced in the future. As a result, a wide range of impacts on the natural and man-made environment across sectors and regions are expected to lead to varying economic, social and environmental costs.

In line with these predictions, anticipated climate change and accompanying implications are raising the level of uncertainty surrounding transport infrastructure and network operations, and the ability to withstand the frequency and intensity of climatic events in the longer-term.

In response to these challenges, the Forum of European Highway Research Laboratories (FEHRL) coordinated a Climate Change Resilient Transport Scanning Tour, held 24-31 March, 2012 across the USA, visiting Federal, State and city Transport Departments. The organisations visited were as follows:

- Turner-Fairbank Highway Research Center –FHWA, Washington DC
- Mayor's Office of Long-Term Planning and Sustainability, City of New York
- North Jersey Transportation Planning Authority
- Louisiana Transportation Research Center (Baton Rouge).

The purpose of the tour was to:

- establish a two way dialogue on challenges that climate change will pose
- understand the research agenda within USA and the research facilities available and projects undertaken
- establish mechanisms to share information and experiences
- identify practical applications
- explore opportunities for future collaboration.

Thirteen delegates from ten national institutes attended the tour, including a representative from the USA Federal Highway Administration. The Secretary General of FEHRL also attended as a representative of all FEHRL organisations. The delegation primarily comprised European, and specifically northern Europe representatives from Norway, Sweden, Denmark, Germany, France and the UK, plus Slovenia from southern Europe. In addition to the representative from the USA, representatives from Israel and Australia attended as Associated Members of FEHRL (see Appendix 1 for a listing of countries and organisations represented).

The interests and technical backgrounds of the tour delegates were necessarily varied comprising a range of disciplines. These included participants with expertise in geotechnics, bridges and structures, economics and environment. The national organisations represented ranged from research institutes, to road operational responsibilities. Some were 100% state funded, others were partially funded by the state and the remainder were private companies.

It is acknowledged that there is less consensus on anthropogenic climate change in the USA than in Europe, although it was reported that historically, coastal States have taken climate change more seriously because of sea level rise (SLR), storms and other weather events. Additionally, some of the more recent extreme weather events experienced in the USA have served as tipping points to increase the focus on climate change adaptation. For example, there is recognition that there are extreme weather events that need to be planned and designed for in terms of the trade-offs between the costs of investments to make the infrastructure more robust and the likelihood (probability) and costs of major disruptions to the system due to climate change events.

Despite the range of locations and institutions visited, a number of key observations and learnings were identified. There was a large focus on identifying vulnerable infrastructure, and establishing ways accommodate sustained climate change impacts over a long duration, and for infrastructure to be planned and designed for more than once-off events.

This report collates the key findings of the US Scanning tour. It sets the scene for climate change projections in terms of temperature, precipitation, sea level rise and storms. The subsequent sections have been formatted according to the following key themes:

- Vulnerability studies
- Adaptation measures
- Policy Research efforts
- Opportunities for collaboration

2 CLIMATE **PROJECTIONS**

Unless indicated otherwise, all of the climate projection details in this section have been taken from the presentation given by Rob Kafalenos and Becky Lupes of the Sustainable Transport and Climate Change Team, Office of Planning, Environment, & Realty which is provided in Appendix B.

2.1 Temperature

The FHWA reported on a general warming projection for the USA of a 4 – 11°F (2.2 – 6.1°C) by 2100, with warming greatest over land and at highest latitudes.

Whilst a change in temperatures of the magnitudes estimated will have a significant impact on a whole host of issues including weather patterns, agriculture and natural habitats, of itself it would be a comparatively minor concern to transport infrastructure. A greater impact could be experienced from more extreme weather events, such as the number of days with temperatures in excess of 90°F (32.2°C), as shown in Figure 1 Error! Reference source not found., below.

CHANGING CLIMATES IN NORTHERN CITIES

For New York City, some of the downscale climate projections are that, by 2080's there will be 37 to 64 days with temperature in excess of 90°F (32.2°C) compared to 14 currently. The climate will be similar to Atlanta's now (Adam Freed, NYC).

Chicago in recent past typically experienced 15 days per year where the maximum temperatures exceeded 90°F (32.2°C). Low case climate predictions are for the number to double, and quadruple for the high case predictions.

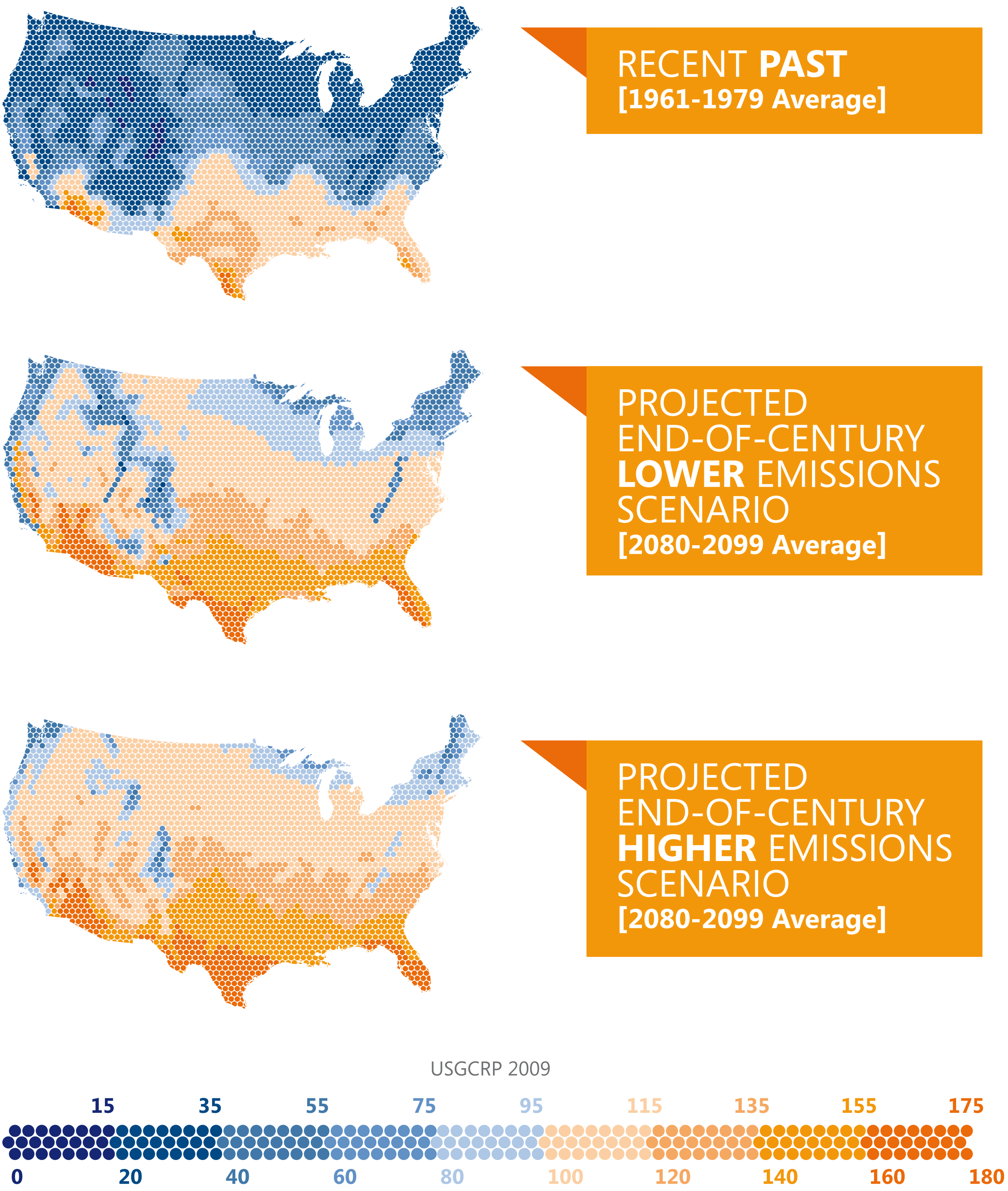

Figure 1. Average Days where maximum temperature exceeds 90F[1]

1 Global Climate Change Impacts in the US, 2009, USGCRP

2.2 Precipitation

Whilst there is disagreement within various models of the extent of temperature change, there is a consensus between the models that future temperatures will be higher than present.

There is far less agreement on future precipitation. It was reported that there were projected changes of an increase in winter / spring precipitation in northern States, with more to fall as rain, and a reduction in the south in winter / spring. There is expected to be an increase in the frequency and intensity of extreme events.

In some cases however, even using "likely" or "very likely" range there is disagreement on the general direction of change, particularly for areas such as the South-East and Hawaii. This is shown in Table 1 below.

	Near-Term	Mid-Century	End-Century
Alaska	3 – 4	6	10 – 15
Midwest	3 – 4	7 – 9	10 – 14
Northeast	3	5 – 6	9 – 11
Northwest	3	3 – 5	5 – 7
Great Plains	1 – 2	3	3 – 4
Southeast	(2) – 0	1 – 2	(7) – 1
Hawaii	0 – 1	(2)	(5) – 6
Southwest	(5) – (4)	(10) – (6)	(19) – (7)
Caribbean	(7) – (6)	(16) – (8)	(28) – (9)

Table 1 Projected Change in Regional Precipitation (mean seasonal, %)[2]

It was reported that two-thirds of States use rainfall maps from the 1960's, and only 13 States have updated these. There is an interagency agreement with DOC/NOAA to update precipitation frequency estimates.

2.3 Sea Level Rise

An Intergovernmental Panel on Climate Change (IPCC) study in 2007 projected sea level rise to 2100 of 18 to 58 cm, with newer studies (Carlson et al, 2008. Rapid early Holocene deglaciation of the Laurentide ice sheet) giving a 50 cm to 2 metres. Local sea level rise may differ from global estimates due to:

- Subsidence/uplift of land
- Sedimentation and erosion
- Ocean circulation
- Gravitationally induced changes
- Ocean density (ocean salinity and temp).

The variances in local sea level projections included a sea level reduction in Alaska due to melting of ice on the land causing the land to rise faster than the sea, whilst in Louisiana, significant but variable subsidence is a major impedance to the application of projected global changes in sea level, as outlined below.

Level Data and Subsidence

Sea level is rising by more than 10 mm per year in Louisiana, and 24 square miles (62 square km) of area is lost per year. Subsidence affects a lot of the models for storm surge, LIDAR and so on.

Historically, benchmarks have been used with datums fixed to a date. Best available data is often mentioned, but this not acceptable as there is often a lack of vertical control or a common reference point, whereby as the earth moves, the benchmarks move accordingly. This in turn affects planning for design analysis, construction, and modelling of operations and maintenance. There are several processes of land change and it is 4-Dimensional in that it varies in time and space, and also has to be measured in relation to sea level rise.

2 Regional climate change effects: useful information for transportation agencies (2010). Prepared for: Office of Planning, Environment and Realty Office of Infrastructure Federal Highway Administration, U.S. DOT

Shallow causes of subsidence are natural compaction of silts and clays, urbanisation and the use of levees which increase subsidence through compaction.

Deep causes are lithospheric loading, faulting, salt evacuation, water pumping and oil and gas extraction.

Correct level data is crucial in determining the vulnerability of transport models. For example, improved understanding of re-levelling and finding better benchmarks through new active new reference stations are critical, especially areas at or below sea level, where evacuation routes may be inundated with storm surge. However, the cost is $20 – 50K for a C4G net station.

2.4 Tropical Storms and Hurricanes

It was reported that by 2100, there is projected to be an average increase in intensity of 2 to 11% of tropical storms and hurricanes, and an increase in frequency of the most intense storms, yet a decrease in the average frequency of between 6 and 34%.

It was reported several times that initially at least, many inland States considered climate change, or extreme weather events to be a coastal problem. Many of the effects on inland States have their origins in coastal storm events, e.g. North Eastern States get a lot of rain from remnants of tropical storms. The Pacific coast is influenced by El Niño and La Niña.

3 VULNERABILITY STUDIES

In considering vulnerability, there are a number of key factors to consider which are outlined below:

- The location of the infrastructure; for example, a bridge in a southern coastal state will be subjected to tropical storms and hurricanes in its design life; a road on a barrier island will be subjected to greater forces than one inland, a bridge in Chicago might be exposed to a greater extremes of temperature than one in more temperate climates.
- Construction type; the construction will play a role in how well it will stands up to, for example, storm events, including factors such as the height above potential storm surges and waves in coastal storms. Climate Predictions; sea level rise, subsidence, storm surge, temperature increase and specifically increased frequency of extremes of temperature, increased frequency and severity of storm events could increase the vulnerability of infrastructures.
- Criticality of the infrastructure itself; factors include the traffic volume (for example an Interstate road might be more critical than a local road), is the road an escape route, is there redundancy with adjacent roads or bridges, are other utilities being carried on the bridge.

In order to assess vulnerability, the above factors must be considered, the first two being related to Asset Management and recording; it is imperative that asset owners know what infrastructure they have, and what the construction and maintenance details are.

The third point concerns local or regional climate predictions, which will give an indication of what future climate effects might be experienced, and finally, on the basis that it is unlikely to be practical or affordable to protect all assets at risk, a value management exercise on key routes that must be protected can be carried out. The fourth point is intended to present the trade-offs between the costs of investments to make the infrastructure more robust and the likelihood (probability) and costs of major disruptions to the system due to climate change events. It is noted that this aspect was not discussed in detail throughout the tour.

This section provides an overview of the abovementioned steps, and also includes an analysis of the range of models, programmes and initiatives developed in Washington, New York City, North Jersey Transport Planning Authority, US Department of Homeland Security and in Louisiana.

3.1 Asset Management

In discussions with the FHWA, there was a general view that there are challenges in consistent data recording and analysis. Records of assets were poor; for example it was reported by Michael Trentacoste that there are 600,000 bridges with 30,000 operators in the USA including State DOTs, counties, towns and private concerns, and there is no common database. For example, Oregon DOT reported at a presentation in Seattle in the summer of 2010 that as they were looking to develop or integrate an asset management framework, they identified several thousand (as many as 9000+) standalone databases and software programs containing various transportation assets. By 2011 they hired a consultant to consolidate the databases and streamline the collection and storage. There are further programmes of database integration underway, and it is hoped that there will be an Interstate database in 2012-13.

Whilst records of assets are critical, in assessing vulnerability it is important to know the condition of an asset; older assets that may be coming to the end of their design life might be less critical; equally, those that are being replaced might be ones to consider adding adaptation measures. To illustrate the scale of the issue for the USA, there are 4 million miles (~6.5 million km) of roads in USA, of which 24% are urban and 24% interstate. It is an ageing infrastructure, with 24.7% of budget spent on maintenance, and 50.1% CAPEX, of which about 50% is spent on rehabilitation. There is funding from Federal aid, administered by State DOTs. Additionally, $0.184 per gallon goes into the fund, representing around 50% as States also have gas tax.

3.2 Climate Predictions

After assessment of asset management has taken place, the third step above relates to the consolidation of data and estimation of the likelihood and magnitude of change. Climate predictions were discussed in section 2, and will not be covered here, except to point out that there is significant uncertainty on future climatic conditions, particularly precipitation, and also downscale projections of climatic data and sea level at a local level. These have been recognised as research priorities by the FHWA and other organisations spoken to during the tour.

3.3 Vulnerability Models, Programmes and Initiatives

During the tour, a number of vulnerability models, programmes and initiatives were outlined, and are discussed in the following sections for each location visited.

3.3.1 FHWA

The FHWA have a climate change vulnerability and risk assessment conceptual model or "framework" with 5 key steps, outlined below and presented in Figure 2 (on the next page):

1. Develop an asset inventory and prioritize the assets based on importance
2. Gather climate data: including magnitude of projected changes, and certainty or likelihood of the changes to extent available
3. Assess vulnerability and risk of the most important assets and the system as a whole to climate changes
4. Identify, Analyze, and Prioritize Adaptation Options
5. Monitor and Revisit

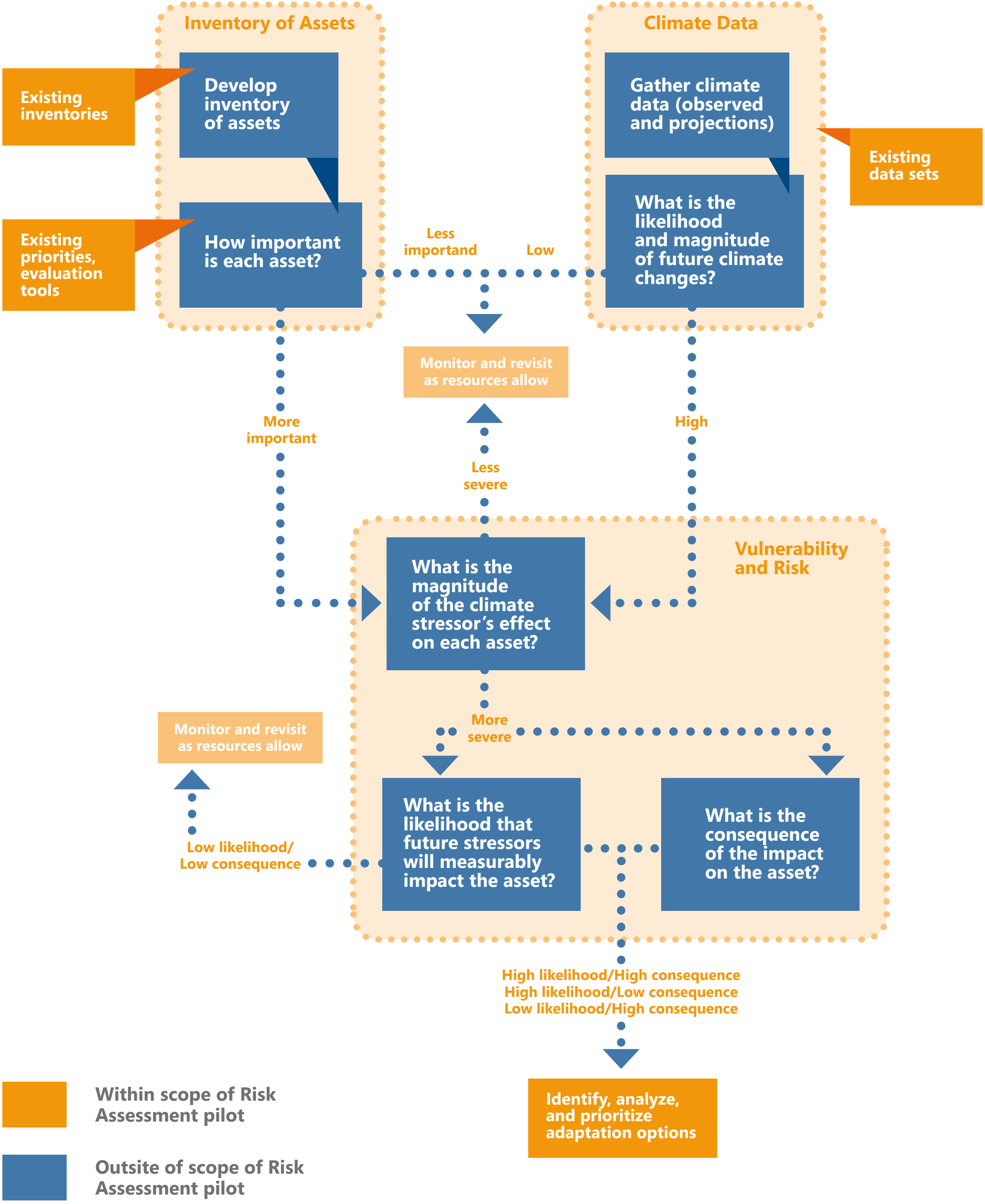

Figure 2 FHWA Pilot Vulnerability Assessment Framework (reproduced courtesy of US FHWA)

The model links in with FHWA's Pilot Programme, which had the twin aims of both helping State DOTs and MPOs (Metropolitan Planning Organizations) advance any activities they may have had underway, and also "test driving" the vulnerability assessments. For the pilot projects, only the first three stages of the model were tested.

3.3.2 Gulf Coast 2 Study

The Gulf 2 study is a "bottom-up" approach focussing on Mobile, Alabama, which aims to identify critical transport assets (e.g. freight tonnage, evacuation routes, back up infrastructure and relief supplies, and community priorities), and then assess the sensitivity of these assets to climate stressors (e.g. identify previous weather and impacts on specific infrastructure, identify thresholds and stressors (storm, wind, precipitation, temperature).

The vulnerability of the critical assets was then assessed through both qualitative measures and engineering assessment. The assessment was multi-modal in that the FHWA asked which critical assets in each mode are most vulnerable to the projected effects of climate change, and also how the overall transport system was vulnerable by assessing which categories and geographic areas are the most vulnerable, and which climate effects are most concerning. The process of developing risk management tools will start at the end of 2012, and coordination with planning authorities and the public, and information dissemination and publication in 2013.

A key finding was the importance of engaging with locals, who knew what and where the key assets were. A base case of a typical storm was used, and then locals were asked the question of what would happen if sea levels rise and there was a storm event?

3.3.3 FHWA Pilot Projects

Five, twelve month pilot projects[3] were selected from calls from FHWA divisional offices. They were chosen to represent a range of different scenarios, including State and Municipal areas, coastal and inland and high and low cost studies. The five pilots were:

Washington State

This pilot looked at all of Washington State's owned and managed facilities; to gain an assessment of current vulnerability which may be exacerbated in the future. Workshops were held across the State focussed on maintenance and operational staff, with significant knowledge of the assets, asking "what keeps you up at night?" The information has been placed in one format, and a focused strategy will be developed to define how the agency will incorporate results. The strategy will be communicated internally and externally.

San Francisco Bay Area

This study focused on a portion of the San Francisco Bay area, and concentrated on sea level rise, and complemented a National Oceanic and Atmospheric Administration (NOAA) project by adding a transportation component.

Risk profiles for a representative list of assets within the study area were created, including exposure to sea level rise and sensitivity to sea level rise (based on level of use, age, seismic retrofit status, maintenance cost, and liquefaction susceptibility). Data was collected on the remaining service life for each asset, but was not used in the sensitivity analysis as the timing of future sea level rise and replacement of specific assets weren't known.

Oahu, Hawaii

Oahu is the economic and population hub of Hawaii, and the study focused on identifying a set of transportation assets that might be vulnerable to climate change. The Pilot in Hawaii performed a qualitative risk assessment on specific assets for storm surges, sea level rise and heavy storm events via low, medium, high, and overall values, and focused on interagency collaboration. Given the remote island location and limited evacuation options, an emergency management component was included. It was achieved by holding a two-day workshop bringing together both the climate science community and key planners and engineers. The McCully Street bridge was identified as the most critical, as it includes several critical utility lines and the main water supply for Waikiki. The discussion highlighted the need for various utilities owners to have open discussions with other asset managers relative to redundancy and robustness of the assets.

3 www.fhwa.dot.gov/hep/climate/pilots.htm

Asset	Overall Value	Impact to Society form:		
		Storm Surge	Sea Level Rise	Heavy Rain/Storm Events
Honolulu Harbor		moderate	low	low
Honolulu International Airport				
The Bus (811 Middle Street)	high	low	low	low
Oahu Baseyard (727 Kakoi Street)	low	low	high	low
Honolulu International Airport and Access	high	high	low	low
Kalaeloa/Barbers Point				
Kalaeloa Airport	low	low	high	low
Campbell Industrial Park	high	high	low	low
Kalaeloa Barbers Point Harbor	high	high	low	low
Three Waikiki Bridges	moderate	high	high	low
Farrington Highway on Waianae Coast	high	high	high	low

Table 2 Vulnerability Assessment of Critical Infrastructure in Oahu[4]

Hampton Roads, Virginia

This programme focused on the Hampton Roads metropolitan area at the mouth of the Chesapeake Bay and involved the University of Virginia developing a priority setting model. The model used multi-criteria analysis including climate change impact scenarios to consider project prioritization in a transportation plan. The model is available for use by other regions, and the results are being used by Hampton Roads PDC as they update their transportation plan.

New Jersey

New Jersey was subject to a specific visit, and the outputs of the study are presented in section 3.3.5.

General comments

One of the key learning outcomes from the FHWA was communication and engagement with locals. They will often know where the key vulnerabilities are, and what might need to be done in terms of the implementation of adaptation measures.

Additionally, it was noted that there is a need to look at the complete picture from planning, design, construction and maintenance of infrastructure perspective. For example, following bridge failures from hurricane induced waves, in some cases holes were drilled through the bridge decks to reduce their buoyancy, but this caused increased corrosion of the steel and hence had implications for the overall structure.

3.3.4 New York City

New York City (NYC) is focussing on long term planning as the population of the city is projected to increase by 1 million by 2030 (from 8 to 9 million). This is seen as both positive and necessary in terms of maintaining NYC as an attractive, globally important city that people want to move to and remain. Another factor is that NYC already has a comparatively low greenhouse gas emission per capita, which is one third of the US average due to housing density and widespread use of mass transit.

4 Oahu Metropolitan Planning Organization, Transportation Asset Climate Change Risk Assessment Project Final Report, November 2011

NYC PLAN FOR CLIMATE CHANGE (FROM PLANYC):

Reduce and track greenhouse gas emissions

1 Release an annual inventory of greenhouse gas emissions
2 Assess opportunities to further reduce greenhouse gas emissions by 80% by 2050

Assess vulnerabilities and risks from climate change

3 Regularly assess climate change projections
4 Partner with the Federal Emergency Management Agency (FEMA) to update

Flood Insurance Rate Maps

5 Develop tools to measure the city's current and future climate exposure

Increase the resilience of the city's built and natural environments

6 Update regulations to increase the resilience of buildings
7 Work with the insurance industry to develop strategies to encourage the use of flood protections in buildings
8 Protect New York City's critical infrastructure
9 Identify and evaluate citywide coastal protective measures

Protect public health from the effects of climate change

10 Mitigate the urban heat island effect
11 Enhance our understanding of the impacts of climate change on public health

Increase the city's preparedness for extreme climate events

12 Integrate climate change projections into emergency management and preparedness

Create resilient communities though public information and outreach

13 Work with communities to increase their climate resilience

Some of the down-scale climate projections are that by 2080's there will be 37 to 64 days with temperature in excess of 90°F (32°C) compared to 14 currently, with the climate similar to the current climate of Atlanta. The urban heat island effect also means the city is 7–9 degrees warmer than surrounding areas in the summer. IPCC models have been used for a 4–7.5% increase in temperature, 0–5% increase in precipitation, and 5-10 inch increase in sea levels in the next 10 years. It is understood that the IPCC predictions are conservative and have been revised for rising sea levels, and there is a higher projection for SLR of around 55 inches (140cm), with storms an issue. The design standards / FEMA insurance on 1 in 100 year storms could be 1 in 15– 35 years based on current storms. In addition, NYC is sinking by 1 inch (2.54 cm) per decade.

The challenges faced by the city are considerable. There are 520 miles (837 km) of coastline, and within this space there are metro lines operated by 3 different organisations, a major port, plus roads, bridges and surface rail. Many roads are State owned, but city maintained, which raises a question on who should pay for adaptation measures? Some of the key challenges for NYC include bridge scour and bridge clearance heights, water on roads, and run-off into storm water, thermal expansion of roads and the urban heat island effect.

NYC has focussed on "Climate Resilience" on the basis that there are extreme weather events currently, and this also moves the focus away from whether climate change exists or not. An example was that for one inch of rain, 1 billion gallons of water goes into the combined storm overflow drains, and 1 inch (2.54 cm) of snow costs approximately $1 million to clear.

In 2006, the plaNYC[5] sustainability plan was created to consider how the environment of NYC will be improved towards 2030, and covers both adaptation and mitigation. It includes plans for reduction in the percentage of solid waste sent to landfill, improvement in water quality, targets for improvement of building energy efficiency as well as targets of ensuring every New Yorker is within a 10 minute walk of a park and planting a million trees. This Plan also includes increased capacity of transport, increased reliability, more housing and public places. It is updated every 3-4 years, and progress reports on 403 milestones are to be completed by 2013, of which there are 30 sustain-

5 http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/planyc_2011_planyc_full_report.pdf

ability indicators. There are specific actions for climate change, as detailed on page 15. The New York waterfront Plan (2020) will also include climate change for the first time.

Adam Freed of the Mayor's Office of Long Term Planning and Sustainability is the Director of the New York City Climate Change Adaptation Task Force. This Task Force was convened by Mayor Bloomberg, and funded by a grant from the Rockefeller Foundation.

NYC have developed a document[6] that details projected climate change impacts for NYC and a model to assess climate risk and develop strategies to increase climate resilience, comprising six key steps, and is presented below: This involves assessment of:

- How climate change will affect infrastructure?
- How critical individual assets are impacted?
- What actions are being taken to minimise risk? e.g. $ impacts by region, measure of potential hurricane risk e.g. 30% loss in value to buildings and employment loss, average dollar loss in inventory, and maintenance cost of increased flooding.
  - Break down assets by classes
  - Operators assessment of assets that are critical (e.g. which section of rail)
  - Qualitative assessment of the type of impact, cost to repair assets, impacts on goods and services, and wider economic, social and environmental impacts according to the Triple Bottom Line.

This model is being tested in 3-4 pilot areas. It can be adjusted to provide options for implementation of resilient infrastructure.

A key factor to the model is that it monetises climate adaptation measures. For example, it compares the cost of installing green drainage against grey drainage improvements.

INTERDEPENDENCY OF INFRASTRUCTURE IN NYC

The interdependency of power, infrastructure and communications was considered. Should power or communications fail, a metro system would fail, or urban roads would become gridlocked. Equally, power and communications are intimately linked and the multi-modal transport network is essential for the workers in other industries.

This was a key learning outcome, in that it is often easy to fall into silo thinking, of single modes, where the whole system is critical.

A Natural Hazard Risk Model has been created to identify assets at risk via qualitative and quantitative assessment (probability and likelihood of occurrence and consequence). Thirty three types of infrastructure are considered, such as airports, and whether longer runways will be required due to hotter, less dense air. This model considers development of adaptation strategies, and prioritisation of these, as well as when to apply the strategies. What can be done differently, rather than rebuilding?

Assessment Steps

1. Identify current and future climate hazards
2. Conduct inventory of infrastructure and assets
3. Characterise risk of climate change on infrastructure
4. Develop initial adaptation strategies
5. Identify opportunities for coordination
6. Link strategies to capital and rehabilitation cycles

Implementation Steps

7. Prepare and implement adaptation plans
8. Monitor and reassess.

NYC monitor relative risks on various parts of the city, sharing with 40 other cities including London and Berlin, and the plan details a whole range of adaptation strategies that have or could be implemented elsewhere.

6 Climate Change Adaptation in New York City: Building a Risk Management Response

100 items of critical infrastructure have been prioritised of which 30 are just transport. There is no report for this but AF is willing to share information.

The Plan does not consider non-city assets such as power, much of which comes from upstate. The general feeling from NYC was that adaptation will be mainly incremental increases and doing things differently.

3.3.5 North Jersey Transport Planning Authority

NJTPA is engaged in a multi-year climate vulnerability and climate change adaptation programme, and have received a grant as part of the FHWA Pilot Programme to assess vulnerability of New Jersey's transportation. This involves the testing the FHWA conceptual model in two study areas; the coastal and wetland areas and the north east corridor. This will be used to prioritise critical infrastructure and determine which resilient strategies should be implemented. Resilience surveys have been conducted in the community, see http://www.nj.gov/dep/cmp/doc/gtr-resilience .pdf

It is envisaged that the testing of the model will help build capacity amongst State agencies to analyse climate change data and assess vulnerability.

The model has been used to assess roadways, bridges, passenger and freight rail, small airports, wetlands and two tunnels. Using GIS they modelled sea level rise, which has shown that Atlantic City is particularly vulnerable.

Whilst average temperature rise was not considered to be much of an issue, projected days with temperatures over 90°F were thought to be significant. The downsizing of climate models, and particularly precipitation was again raised as an issue, as is the absence of bridge clearance data.

New Jersey has been looking at mitigation only to date, as there is no current State wide mandate for adaptation, although they are investigating how to adapt without a Mandate. There are however, ongoing discussions on adaptation and mitigation. Hurricane Irene has changed attitudes, and more work is being conducted at the federal level. Funding is however an issue, whereby a compelling case is often required (interplay of the Triple Bottom Line).

NEW JERSEY FRAMEWORK OBJECTIVES:

1. **Rank transport capacity (access and connectivity, magnitude, redundancy capacity), identify traffic analysis zones based on population and use of roadways origin-destination networks.**
2. **Identify what are the climate impact types (sea level rise, storm surges, temperature and precipitation, inland flooding impacts) e.g. for sea level rise, what is the local sea level rise using IPCC special report on emission scenarios for low, medium and high; use of local data; projected impacts for 2050-2100, SLOSH model used)**
3. **Determine climate change impacts e.g. projected impacts from 2050-2100**
4. **Determine infrastructure vulnerability to a 1% storm event to medium greenhouse gas scenario for 2100 e.g. 81 miles of road inundated, 138 miles of rail.**

In terms of modelling, historical data is not a future indicator, but can assist in the identification of vulnerable infrastructure. The question was raised as to how satisfactory are monitoring and parameters, and documentation. Other complexities involve the removal of long-term monitoring stations due to the financial challenges underpinning the economy.

Some of the key lessons include:
- It is easy to hide behind uncertainty
- Recent events have served as a tipping point
- Adaptive approaches holds promise

- Piggybacking[7] can be effective
- Existing funding is a motivational tool
- Timescale is a problem
- Implementation of concepts into practice from the strategy level is a challenge.
- In terms of future directions, pilot projects and case studies are very complete and detailed in the US. The difference between the two that was noted. The question was raised as to how these inform more than the writers, and how to take this to the next step.
- The effect of disasters on politics was noted whereby repeated disasters do not seem to impact on the leadership, only a failure to respond. This is not the case in some European countries.

The full report on the model and vulnerability assessment is available to download at: http://www.njtpa.org/Plan/Element/Climate/documents/CCVR_REPORT_FINAL_4_2_12_ENTIRE.pdf

3.3.6 US Department of Homeland Security

The US Department of Homeland Security (USDHS) has a responsibility to strengthen security and resilience; as such climate resilience / extreme weather events come under its remit. It was reported that at any time, 20% of the USA is under a Federal recognised "disaster".

Much of the work undertaken relates to disaster response to weather events such as floods, tornadoes and the like, but there is a key role in also ensuring that transport networks are protected. Key challenges relating to resilient infrastructure include; overcrowding of highways, aging of infrastructure, societal and economic consequences from infrastructure failures such as people left without power/access.

Resilience can include the fostering of individual and community needs and capacity of recovery, system robustness, and building infrastructure so that it is safe and secure against terrorism e.g. the threat of inundation of tunnels due to explosions, loss of life and access/connectivity of the subway. Bomb damage to a tunnel would not only flood the tunnel but also the surrounding infrastructure, and protection needs to be considered. Bridges are also of concern and the USDHS are using acoustic methods to find damage in bridges, and have installed sheaths around cables, and added more suspension cables where necessary, on bridges to prevent terrorist damage.

It is clear that there are many interested and sometimes unexpected parties that will have an input into infrastructure vulnerability assessment and adaptation, and that there is an opportunity to share experience and learning.

3.3.7 Louisiana - Hurricane Generated Wave Loading on Coastal Bridges

There have been many bridge failures resulting from storms in Southern States. The bridge decks are mainly affected by the horizontal and vertical force and the timing of the wave moments, which will lift the bridge spans, and scour can also be a factor. Damage to the substructure can occur mainly as a result of striking of it by the superstructure.

A project was undertaken by LTRC to provide a storm surge / wave atlas for Louisiana coastal waters to provide water level, depth-average current and wave information for design frequency storm events.

A storm surge mesh was developed using wave data and wind and pressure fields for 50 of the most severe tropical storms and hurricanes to have impacted Louisiana in the past 154 years. The storm paths were adjusted by half a degree (approximately 55 km) to give 150 storms, and then run though wave and storm surge models, using hindcasting.

An extreme value analysis was performed to identify water elevations and associated wave heights, water elevations and the depth-averaged current speeds, and to determine the 100 year maximum wave heights and water elevation in the study area, and run through a statistical method of "bootstrapping" to predict confidence intervals. The result was the creation of a wave-atlas for Louisiana.

7 See section 4.7 on page 23 for more details on piggybacking.

With this information, the data was placed into a GIS database and an assessment made of 130 critical bridges in Louisiana. A first screen was undertaken using Google Earth, which considered the fetch length (where you will not get a wind generated wave) and the height of the bridge.

A level one analysis was undertaken using the AASHTO Code "Guide Specification for Bridges Vulnerable to Coastal Storms", with FEMA elevations used for wave height, i.e. will the crest of a wave impact on the bridge? Secondly, the criticality of the bridge was assessed, such as the importance of the route, redundancy with other bridges to give the final list.

Additional design challenges are that there is sea level rise and subsidence from natural and anthropogenic fluid withdrawal (oil and surface drainage), and a change in the storm frequencies and pattern change.

The Wave atlas provides significant metrological and ocean information that will be used for analysing existing and future bridges. Both horizontal and vertical forces, as well as wave tank tests and determination of coefficients were conducted. The model however, allows consideration of current and future asset risk, and provides the information needed to consider options for retrofit or contingency planning.

Options for retrofit were the addition of tie downs on bridges where the dead weight will support itself, or options to reduce the buoyancy of bridge decks due to spaces in girders were also considered. A report will be prepared shortly.

4 ADAPTATION **MEASURES**

4.1 FHWA

There is a disjoint within FHWA in that whilst 95% of bridges in the US cross rivers, there is a significant coastal population, and these bridges could form evacuation routes; although it should be noted that bridges within five nautical miles (approximately 8km) of the coast are considered to be coastal. The 5% of coastal bridges are therefore more critical, and are often subject to intense environmental forces. These include wind and wave action in general and hurricane prone areas, in particular; scour in general, but more intensely in barrier island areas, and/or areas with strong currents. As such, there is a requirement for adaptation to extreme weather events as far as is practical. "Guide Specifications to bridges vulnerable to coastal storms" has been published by the FHWA in response to this.

Figure 3 Comparison of deck height on damaged US90 Biloxi Bay Bridge and previously abandoned bridge

During Hurricane Katrina, the wave height was an issue on many bridges due to the storm surge, which resulted in waves hitting the bridge decks at 5–6 second intervals. This induced both horizontal and vertical pressures, plus weight of water on top of decks. Some of the adaptation measures identified included the very simple building higher to avoid wave action in the future. This hasn't always been the case as some State DOT standards have required bridges to be replaced to the same standard. This occurred in the building of the Biloxi Bay Bridge on US90.

Another issue has been the buoyancy of decks; where the gaps between the girders on the underside of the deck have acted in a way that induces lift by wave action. The potential to fill these has been investigated, by the FHWA.

The FHWA has also been undertaking research on the shape of bridge decks to design such that their shape is more hydraulically efficient, and less likely to be damaged by wave force and inundation. Cross sections of typical and new deck designs are presented in Figure 4.

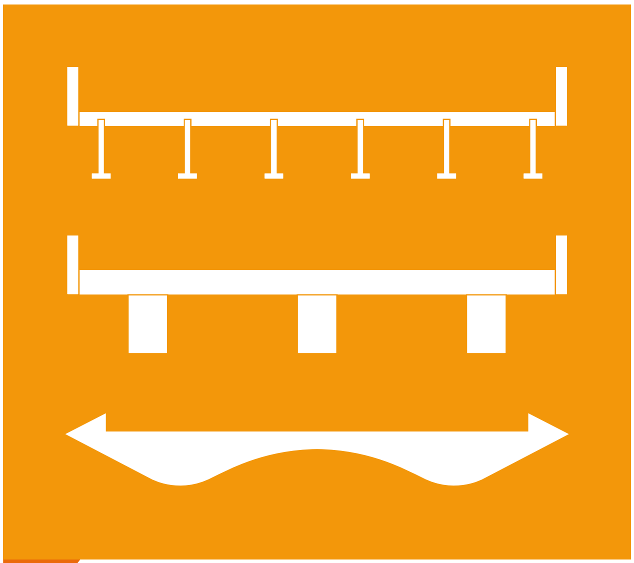

Figure 4 Convention bridge deck construction (top and middle) and new design (reproduced courtesy of FHWA).

Other potential options for retrofits have been considered such as shear blocks, fuses and breakways barriers.

The use of technology transfer from other industries is something that is being considered, such as oil platforms for example, which have been designed for extreme maritime environments.
Finally, abandonment of infrastructure in certain situations and replacement with something new might be considered appropriate.

Much of the focus from the FHWA on adaptation was of bridges structures themselves. Although for the Bonner Bridge, a key aspect has been to capture and build up sand areas around the barrier islands to protect the roads going to the bridge, not least because the bridge and the roads leading to it are the sole means of escape. Another idea for the roads on barrier islands with dunes on either side was to lower them, so that in storm events, the dunes would cover them and potentially protect them. This has not been trialled yet, but is worth considering given the damage caused by inundation, and the fact that the road has already been moved back once due to erosion. Other work has been undertaken on road strength following inundation, and this is presented in section 5.3.

4.2 New York Adaptation Measures

There is sometimes some confusion between mitigation and adaptation, and this was the case in NYC. One mitigation measure is the "white roofs" programme to help prevent the urban heat island effect. So far, 2 million square feet (~186,000 m^2) out of 1.6 billion (~150 million m^2) have been painted. There are some green roofs too, but they are much more expensive, however the efficiency of white roofs was reported to drop by 50% in 3 years. NYC would be interested in applying white asphalt and have approved a high albedo asphalt for trial.

The 21st Century Parks for NYC is a project of the design trust for public space with high performance landscape guidelines. The aim is to design parks and waterfront areas to accommodate water, and also to elevate the land in some developments.

NYC will invest $1.5 billion in green infrastructure over the next ten years, to assist in capturing storm water. This equates to $2.2 billion of grey infrastructure and will make 10% permeable. This action includes a Department of Environment project to identify stormwater options.

There have been 30 stormwater management trials and modelling to prove capture. It is not possible to go install at depth in NYC due to the extensive underground infrastructure and shallow bedrock.

As noted in Section 3.3.4, there is an initiative to plant more trees to provide shade and to reduce the temperature and heat island effect. NYC is planting over 500,000 trees as part of the Million Trees NYC initiative to address this effect.

In addition to the abovementioned documents, a number of manuals and guidelines exist to assist in planning and design within NYC. These include:

- Street Design Manual - to show different types of asphalt such as permeable and high albedo, and options for their use.
- Landscape Guidelines; these are not mandatory, but can be used as a Guide for practitioners. It highlights climate change resilience.
- Sustainable storm water management plan – demonstrates the environmental benefits of alternative pavements e.g. which are more appropriate in terms of greenhouse gas reduction, and less expensive.

Other initiatives include energy efficient LED lighting, increased use of storm surge barriers, restoring and creating new wetlands, and designing parks and waterfront areas to accommodate rising sea levels. For example, in some areas, walkways are being "designed to flood" with one walkway for low tide and one for high tide.

One of the most useful sources of information is provided in the New York City Panel on Climate Change 2010 Report, Chapter 4: Infrastructure impacts and adaptation Challenges[8]. It details many of the potential effects of various climatic events, such as increased storms or heat on critical transport and non-transport infrastructure.

In addition to general adaptation, NYC also has evacuation plans for 2 million people to evacuate the city, provide shelter within city, enable routes for emergency services and resources, and to facilitate the return of the community through the provision of disaster housing.

Some of the key learning outcomes from NYC were:

- Strategy for piggybacking adaptation schemes – e.g. if bridge or flood defence going to be built, spend a bit more and make them higher.
- The Mayor has been a key factor in getting senior representatives from various organisations around the table. Political leadership is therefore critical.

4.3 New Jersey Transit

New Jersey Transit has assessed vulnerabilities of their network and potential adaptation measures, through the use of cost-benefit analysis of measures identified. Additionally, operating both bus and train services gives some redundancy, and they also have electric sources from different companies for the trains, which enables greater resilience against power loss from one provider. New Jersey Transit only considers the track infrastructure as they "get the buses and trains out of the way" in the event of flooding events, which is the main concern. However, it should be remembered that this approach did not work in New Orleans during Hurricane Katrina.

There is an issue in releasing information in reports, as there is a danger in giving a guide for sabotage.

4.4 Rutgers State University

Rutgers University are part of the Climate Change Alliance Action which includes New Jersey State representatives. They recognise that there are research gaps in the connection with researchers and practitioners. Their aim is to develop capacity, training and demonstration projects covering infrastructure, people and environment. Information on the Climate Change Alliance is available at: www.climatechange.rutgers.edu/njadapt.

4.5 Hurricane and Storm Damage Risk Reduction

Huge areas of New Orleans were flooded during Hurricane Katrina due to levee failures and overtopping of levees. In St. Bernard Parish there were 20 foot (6 metre) flood walls but a 28 foot (8.5 metre) storm surge, giving 8 foot (2.5 metre) constant overtopping, excluding additional waves. Whilst storm surges can occur at a Category 3 level, Katrina was a Category 5 hurricane, followed one month later by Rita, a Category 4 hurricane.

8 http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2009.05318.x/pdf

New Orleans is largely below sea level, with the Mississippi and Lake Pontchartrain both above. Following Katrina, a $14 billion contract was approved to repair and protect New Orleans, designed on a 100 year storm event (Katrina was a 400+ year storm). The following protection measures were undertaken:

- Higher floodwalls – will remain dry on a 100 year flood event and will overtop on a 500 year flood event, but at an acceptable level. The St. Bernard floodwall was constructed at a height of 30 foot (9 metres).
- Some internal levees were removed to reduce overall perimeter.
- The Lake Bourge Surge Barrier was constructed.
- Pump stations with the capacity to run for 3 days were constructed, with safe houses for the operators to remain onsite in the event of a severe climatic event.

This work was undertaken using Federal money. States are responsible for new levees and maintenance is undertaken by the Orleans Levee District.

RETREAT FROM NEW ORLEANS?

The idea of having some sort of managed retreat from New Orleans has been discussed in some quarters, based on potential future storm damage. This was discounted on the basis of the amount of commerce that comes through the Port and the Mississippi, specifically oil from the Gulf of Mexico and agriculture from Iowa and other states.

- **Ports – Port Louisiana is the top tonnage port in the nation**
- **Seafood – 24% of all commercial species caught in the lower 48 States are caught in Louisiana waters**
- **Energy – top producer of domestic oil, offshore gas, and offshore revenues for the US Treasury.**

Learning points:
There are a range of adaptation measures that have been considered in Louisiana and across the other States visited. These include a range of solutions as listed above, as well as:

- Hard engineering solutions e.g. flood defences, higher flood walls, levees, surge barriers, and pumping stations
- Soft engineering solutions, e.g. creation of wetlands and marsh rehabilitation, dune stabilisation on barrier islands
- Green infrastructure to cope with rainfall events
- Design standards, e.g. build bridges higher so they don t suffer wave impacts
- Evacuation planning (see section 4.6)
- Raising ground as a result of subsidence and rising sea levels; not always practical, but potential for new developments.

The challenge of adapting to Climate Change is the adaptation of existing infrastructure. Consideration needs to be given to the residual life of infrastructure, and damage caused by heavy loads and protection of emergency routes if speed and load restrictions are waived.

4.6 Evacuation Planning

Where hurricanes and storm surges pass through coastal conurbations, there is often the requirement to evacuate. There are strategies developed to use traffic management to optimise the available road space and escape routes. This includes the development of plans and maps that are widely published beforehand and announcements on the television, radio, schools and throughout the community, to maximise travel information. An initial task is to model the probability of evacuation, based on the path, intensity, location and speed of storm and dwelling flood risk. There is approximately 4 days notice that there will be a hurricane, and the models are updated according to real time intervals. In accordance with this information, decisions are made on whether to evacuate and whether it is voluntary or mandatory given the timing and storm information available.

There are considerations on the model route choice based on the accommodation available at the destination, such as hotels, relatives. Additionally, there is a great deal of information on who travels where, including factors such as ethnic similarity.

The models developed can be adapted to consider the shortest path, familiarity with route, facilities along the route, and where to have crossover points to have 8 lanes running in one direction. These are known as "contra flow" techniques where both carriage-ways are utilised to evacuate a city.

For Hurricane Ivan, the evacuation from New Orleans to Baton Rouge was 8 hours, and improvements to the plan reduced this to 3 hours for Hurricane Katrina.

There has also been a study on evacuation of the carless and individuals with special needs, which is the DOT responsibility. It was also pointed out that some people cannot or will not be evacuated, such as citizens who are hospitalised, zoo keepers, art keepers or the incarcerated, and so there is a requirement for secure areas.

Modelling trials have also been conducted in locations of previous disasters e.g. in Florida, to ensure that the same plans can be applied universally. Other forms of evacuation include "no notice evacuation" where work is being done in Australia to address the random nature of extreme weather events e.g. bushfires and flash flooding that provide only 30 minutes warning. Some options are to bunker down or evacuation where possible.

One learning point that was considered was that the Forever Open Road Adaptable Element may also be made adaptable to evacuation.

4.7 Piggybacking

In contrast to the large sums of money invested into reconstructing and protecting New Orleans, an approach that was discussed with the FHWA, NYC and NJTPA was "piggybacking". Whilst the damage to New Orleans was catastrophic in nature, and the response was emphatic, such an approach for other cities and regions will be unaffordable. However, the alternative approach is that where vulnerabilities have been identified at a city or region level, there might be an opportunity to add additional climate protection to an already planned scheme. For example, investment in a new proposed bridge requires considerable capital costs, for a (relatively) small amount of additional money, it could be used to make it higher, or have increased resistance to wind; if drainage is to be replaced, could the design flows be increased in anticipation of future extreme rain events.

4.8 General Points

A number of adaptation actions that have, or could be considered were raised throughout the week, including:

- Raising ground; this was reported by USDHS to have taken place in Chicago and Galveston, Texas, where levels were raised by a storey. A new development in New York was raised in anticipation of future sea level rise, although it was reported that it would be largely impractical for Manhattan, as apart from the cost, there would be significant implications for disabled access amongst other things.
- New York has invested in green infrastructure to cope with rainfall events. Porous asphalt, sustainable urban drainage systems (SUDS) and general measures for rainwater attenuation are increasingly used as a way of reducing the flash run-off flooding in urban areas.
- White or high albedo asphalt has been trialled in New York and, whilst not strictly an adaptation technology, there is potential for it to reduce the urban heat island effect, which is expected to become more pronounced as the number of days with temperatures exceeding 90°F increase.
- The potential for generating energy from the pavement was not mentioned, but is a key component of the Forever Open Road project.
- A number of hard engineering solutions were discussed for protection against storm surges and hurricanes, i.e. construction of flood defences, levees and pumping stations. It is increasingly recognised that these alone will not be sufficient, and the protection of coastal areas in the Southern States through the creation of wetlands and marsh rehabilitation have a significant role.
- On the eastern seaboard, the protection of the main coast by barrier islands was noted. The loss of the barrier islands through a combination of sea level rise, coastal storms and erosion would have a major impact on infrastructure, operations and the community. Therefore, activities such as dune stabilisation will be important, although land ownership, and compensation for home owners on the islands has proved to be problematic.

Another point that was raised was that there seem to be more extreme weather events in the USA (hurricanes, tornadoes and wildfires for example) than in Europe, and as such there is a different approach. Whilst there is a focus on keeping the roads open in Europe in all weather conditions, in the USA and Australia there is recognition that extreme events may cause closure, and possibly destruction of transport infrastructure with associated safety implications.

The role of the insurance industry was discussed, and how they perceive risk has a major bearing on construction and adaptation measures. There remain areas of New Orleans that have yet to be redeveloped following Hurricane Katrina as the protection afforded by the flood protection measures has yet to be agreed. It was also reported that engagement with the insurance industry has proved to be difficult.

Finally, an adaption of the financial products caveat, that "past data is not an indication of future performance" was clearly apt, i.e. past weather patterns might not reflect current or future ones.

5 RESEARCH **EFFORTS**

5.1 FHWA

The FHWA undertakes a range of research programmes and has a number of research facilities at Turner Fairbanks, including pavement assessment, wind tunnels and a hydraulic laboratory as well as a mobile concrete laboratory. These facilities can be used to assess the potential for changes due to climate change, such as wave action on bridge decks as described earlier. Equally, much of the research effort has been in the field with State DOTs and through Pilot Programmes described earlier.

Some specific research efforts on pavements detailed by Cheryl Richter (CherylRichter@dot.gov) were on long life pavement assessment, and research on flooded pavements, and the potential for use by emergency traffic. More detailed information is provided from the study by LTRC. Other research has been undertaken on alternative aggregates for pavements and the modification of aggregates with nano-technology.

5.2 Louisiana Transport Research Center (LTRC)

LTRC is sponsored jointly by the Louisiana Department of Transportation and Development (DOTD) and Louisiana State University. The centre conducts short-term and long-term research and provides technology assistance, engineering training and continuing education, technology transfer, and problem-solving services to DOTD and others in the transportation community.

The center is largely supported by funding authorized by the Federal Highway Administration. LTRC's goal is to merge the resources of state government and universities to identify, develop, and implement new technology to improve the state's transportation system.

The LTRC Foundation is governed by a board of directors whose composition reflects the nature of the transportation community (public, private, and academic). Included in this group are three representatives of DOTD, two LTRC administrative positions, four private industry representatives, and representatives of the seven Louisiana universities with engineering programs (University of New Orleans, Southern University, University of Louisiana at Lafayette, Louisiana Tech University, McNeese State University, Tulane University, and Louisiana State University). Additionally, there are Professors, Post Doctoral and Graduate Students on the staff working 100% for LTRC.

There is a combination of Federal and State funding for research, and approximately half of the research budget is used to fund contract research studies with Louisiana universities. Additionally, the LTRC Foundation is funded by private donations which attract a tax write off. The Foundation can partner and purchase liability insurance, unlike the State, and this arrangement has paid for the building and funding of professional links.

Internal staff are responsible for developing their own research and there is a biennial solicitation to the transportation community asking them to provide advice on research requirements.

LTRC generally do not undertake design, but might undertake research on specific components. LTRC issue a Request for Proposals (RFP) to 7 State Universities, and depending on the response, the might re-issue to consultants.

Details on current and proposed research undertaken within LTRC are provided at http://www.ltrc.lsu.edu/pdf/2011/ann_rpt_11_web.pdf.

5.3 Submerged Road Strength Loss

Louisiana Transport Research Center (LTRC) undertook research on the "Impact of Hurricane Katrina on roadways in the New Orleans Area". Approximately 2,000 miles (~3,200 km) of roads (~1,500 city / parish and 500 Federal / State) were flooded for up to 5 weeks.

LTRC conducted testing on several on-going construction projects to determine if contract modifications would be required to address damage impact. Damage was found in concrete and asphalt layers and subgrades were found to be very weak. For one project, with "before and after" data, the damage incurred was equivalent to three inches (7.6 cm) of asphalt concrete.

As a result LaDOTD contracted Fugro Consultants to conduct testing on 238 miles of State Highways in New Orleans at 0.1 mile intervals. Fugro conducted Falling Weight Deflectometer (FWD), Ground Penetrating Radar (GPR), which was calibrated with roadway coring.

GIS and NOAA flood mapping were used to identify submerged and non-submerged sections. Once weaker strength parameters were identified, standard pavement designs were applied to the structural numbers and subgrade modulii to determine an equivalent amount of asphalt concrete for the strength loss. There were three pavement construction types:

1. Concrete Pavements, which suffered very little damage
2. Composite pavements, which demonstrated no need for additional structure in the pavement layers, however a weaker sub-grade in the submerged areas equivalent to one inch (2.54 cm) of asphalt concrete was identified. There were inconclusive results with the composite sections due to numerous combinations and thicknesses of layers.
3. Asphalt pavements which had strength loss equivalent to approximately 2 inches (5 cm) of asphalt concrete, and thinner pavements were weaker than thicker ones.

Prices based on milling and replacing two inches of asphalt for 200 miles of submerged State Highways gave an estimated cost of $50 million for rehabilitation. The figure is used to indicate the overall likely rehabilitation cost for Federal Aid, with rehabilitation on sections considered on a case by case basis, rather than a blanket two inch replacement across all roads.

Additional information seemed to indicate that greater depths of submergence caused more damage, and it is known that considerable damage was subsequently caused by trucks taking debris out of New Orleans which were not subjected to speed or weight restrictions.

The lifting of restrictions is understandable in this instance, but there might be a case for cities or regions in Europe and the USA to consider routes for clean-up operations based on specific road constructions which are unlikely to have suffered damage, or on "sacrificial" roads. Residual strength following flooding and "flood resistant" pavements might be a **research need**.

5.4 I-10 Twin Span Bridge

The I-10 Twin span bridge over Lake Pontchartrain suffered extensive damage following Hurricane Katrina. A 5.5 mile (8.85 km), crossing, meaning effectively an 11 mile bridge in two spans was affected. A report is available at http://www.aspirebridge.org/pdfs/magazine/issue_18/i-10_twin_span_web.pdf.

Given the strategic importance of the bridge, a rapid and efficient solution was required for temporary repair, followed by a permanent replacement via the construction of a new bridge. Initially, the eastbound span was replaced by use of scavenged sections from the westbound span. The westbound span used 1.5 km of ACRO to replace destroyed segments.

Following these phases, it was considered that the old Twin Spans were too vulnerable to storm surge, therefore, in 2006 work commenced to construct two new bridges with more adaptation measures. Two contracts were let on a Design and Build basis for a 100 year design life; the first to build the vertical and horizontal transitions and ramps, and a half mile (0.8 km) structure designed to resist storm surge and to build a constant width level grade spans. The second contract was let to build twin, one mile (1.6 km) sections over the navigational channel, to provide greater navigational clearance, resist wave loads on the substructure elements and resist barge impacts.

A further contract was let to demolish the old bridges, which were retired in April 2010. The recycled concrete aggregate was placed in gabions and used for coastal restoration and small reef construction. For both the spans, prefabrication was essential.

Given Louisiana's lack of hard rock (conversations with LTRC staff indicated that aggregate was brought into Louisiana from as far away as Kentucky) that grading and use of an aggregate may have been a better option. The total cost of the works was $753 million USD, funded entirely from the Federal Highway Administration.

The new Twin Spans were completed in September 2011. Health monitoring will be undertaken on the bridge to ensure performance in service, including strength, displacement. Instrumentation is installed from the piles to the deck including Weight in Motion, load and wind. The current bridges feature traffic cameras and electronic message boards to alert motorists of immanent conditions. Electricity has not been connected yet, however. LTRC will undertake the monitoring and are willing to share results.

One of the key learning points from this was the speed with which all parties reacted. The new Twin Spans were designed by Louisiana DOTD in 6-8 weeks. Work on the temporary repair started within 7 days of landfall of Katrina. The Louisiana DOTD and the private contractors worked extremely hard to get the contracts, designs and construction underway, working 11 to 14 hour days, 7 days per week for 14 months.

5.5 Coastal Protection and Restoration

The Coastal Protection and Restoration Authority (CPRA) has 13 members, and $17 billion in State and Federal funding has been allocated to the protection and restoration of Louisiana's coasts. The protection measures are set against a backdrop of potential economic losses without action. The predicted future flooding from a 100 year flood event, without future action, increases the risks to lives, jobs and communities. The potential for damages is estimated to reach $7.7 to $23.4 billion annually in economic loss.

Historically, delta formation from sediment deposition from the Mississippi river has been important in the protection, increase and stabilisation of coastal Louisiana. This was interrupted in 1927 when flood protection levees disconnected the river from the estuaries and deltaic cycle.

There is now recognition that the natural balance needs to be restored, and there is a Master Plan for a sustainable coastline produced every five years, with the 2012 plan presented to the CRPA Board on March 21st, 2012, and available at www.coastal.louisiana.gov (Louisiana's Comprehensive Master Plan for a Sustainable Coast). It focuses on protection on natural processes and habitats, flood protection, cultural heritage and industry, specifically navigation, fisheries and oil and gas.

Three focus groups have been created on Navigation, Fisheries and Oil/Gas. A Framework development team comprises over 30 Federal, State, non-Government Organisations, academic, community and industry organisations. Extensive public review and input has been received in over 120 meetings.

Nearly 400 projects were evaluated across the coast, both past and present. A range of protection structure projects were considered e.g. earthen levees, concrete walls, floodgates, and pumps. Three types of non-structural measures are proposed in the Master Plan. These include flood proofing (residential/commercial), elevation (residential) and voluntary acquisition. A range of protection levels were developed which include the chance of a 50, 100, and 500 year flood event affecting a home owner over the life of a 30 year mortgage.

The Master Plan details 109 current and future projects that will afford structural or non-structural protection to the coast, at an estimated cost of $50 billion over 50 years. It has had to take account of a number of uncertainties, including:
- Sea-level rise – different estimates and regional variations
- Subsidence, which varies across the State
- Storm intensity and frequency
- Rainfall.

Moderate (assumed limited changes in the factors over the next 50 years) and less optimistic scenarios (assuming more dramatic changes in these factors over the next 50 years) were considered.

New tools are being used to develop integrated modelling frameworks and to consider a range of factors in making decisions. Risk reduction, expected annual damages and restoration of the land area are considered.

The Master Plan delivers information on the expected annual damages from floods at year 50 under different future scenarios, and the potential rate of land change over the next 50 years.

The most significant uncertainty, and hence **research need** concerns regional sea level rise guidance, as the application of national guidelines does not take account of either the subsidence and the marsh accretion. Two new reports have been recently completed in January 2012 – Recommendations for anticipating sea-level rise impacts on Louisiana coastal resources during project planning and design (Summary and Technical Reports).

Sea-level rise equations have been developed to:
- Determine the rate of regional water level change (mm/year)
- Utilise an acceleration value based on predictions of future sea-level rise
- Apply a local subsidence rate
- Apply a rate to habitat or location specific marsh accretion to predict marsh collapse.

Marshes are vital in protecting the shoreline from the full force of offshore forces, and will maintain themselves though a range of biological processes up to a tipping point of sea level rise[9]. Options are considered for using spring flooding to deliver sediment to the marsh areas and barrier islands. The balance of river flow and water extraction for industry is also an issue. This is a potential area for further research.

6 POLICY **AND STANDARDS**

6.1 FHWA

There are limits to what FHWA can do for standards, although Federal Aid can be provided for adaptation. The USA has used UK adaptation plans[10]. There are Policy Statements for Federal Highways, which would, for example, allow bridges to be constructed off standard specification to take account of climate factors such as sea level rise. This is enabling rather than directing as Federal money has ties to what is eligible and what isn't.

Another issue is that State DOTs have design standards, whereas American Association of State Highway and Transportation Officials (AASHTO) control the specifications. A further factor reported was that design standards are based on peaks, whereas climate data is different. Peak flow can come in 2–3 hours, but climate model data is based on 24 hour periods.

9 Rising sea levels can affect biodiversity where there is not as much sedimentation, and hence the marsh is also affected as a result

10 Highways Agency Climate Change Adaptation Strategy and Framework, 2009

Federal Highways has 2,700 employees and have representation in every State. A challenge is that they don't have control of climate change issues; accordingly, some work gets undertaken by the States and some States commission universities. As a result, there is duplicity and inconsistency of research and some research is undertaken by non-climate change specialists.

The US Army Corps of Engineers issued Circular (no 1165-2-212) in October 2011 giving guidance on incorporation of "direct and indirect physical effects of projected future sea-level change across the project life cycle in managing, planning, engineering, designing, constructing, operating and maintaining USACE projects and systems of projects". The document gives guidance on geographic extent of applicability and supporting information on projected sea level rise.

It points out that global mean sea level rise is one thing, but it will vary locally which should be taken into account. For example, Louisiana is suffering from settlement / subsidence due to natural consolidation and anthropogenic activities. Alaska is experiencing sea-level fall due to land rising as a result of the reduction of ice weight through melting.

There is no national policy on vulnerability in the USA, and it was reported that they had made reference to the UK Highways Agency documentation (actually English Highways Agency as transport is a devolved issue for Scotland, Wales and Northern Ireland). Germany also has a climate change adaptation policy and the European Critical Infrastructure Directive will cover utilities and transport, although it will not focus solely on climate change / weather events, but also all other threats, such as terrorism.

Long-term maintenance considerations were discussed, and this is potentially an area where specifications will need to be developed and/or linked to Asset Management procedures in the USA and elsewhere. Management of a pavement over a design life that could stretch into decades, against potential increased storm events, flooding and extreme temperatures will be challenging.

6.2 Political Influence

It was noted that pressure from Mayor Bloomberg in New York City was a key factor in ensuring the plan for risk assessment and adaptation was developed and is now being implemented, and also that senior representatives of stakeholders made themselves available for meetings and input.

Similarly, President Obama has been instrumental in securing funding for highway infrastructure, with a focus of adaptation.

7 COLLABORATIVE **OPPORTUNITIES**

Since the launch of FEHRL in 1989, cooperation with the US has been a recurrent issue. At the beginning, a clear focus concerned the European response to SHRP (the Strategic Highway Research Program). Many FEHRL members actively participated in that programme and the cooperation with FHWA continued through projects on a number of issues. From 2004 onwards, cooperation on the second SHRP programme stimulated further discussion on joint projects.

In October 2009, FHWA became an Associate of FEHRL. FHWA's objectives were to formalise the cooperation and to enable the organisation to more actively engage in FEHRL's research prioritisation and project proposal activities. To further stimulate this development, in 2011, FHWA and FEHRL signed a Memorandum of Cooperation (MOC) which was followed by the development of two mechanisms.

These outline overarching and administrative protocols to be followed. The first is for the FHWA to receive funding from FEHRL to apply towards projects where the US is the lead and will assume primary project leadership responsibilities. The second is a Cooperative Agreement with FEHRL for projects that fill gaps or advance the FHWA's research objectives.

The Cooperative Agreement that has been established sets the procedures to be followed and has been elaborated following an extensive review of US and EU legal requirements. The procedure developed governs the joint development of research priorities and details the research projects that would arise from this.

The first project to be developed under the Cooperation Agreement is the project MIRIAM (Models for Rolling Resistance in Road infrastructure Asset Management Systems). FHWA's interests in collaboration on this European project led by the Danish Road Directorate include three primary areas; the influence of pavement characteristics on energy efficiency; the importance of rolling resistance on the efficiency within life cycle analysis framework, and the constraints/requirements to implementation.

FHWA and FEHRL now are cooperating with several European Road Authorities on the development of a co-funded programme of research on advanced and innovative road infrastructure. This programme would be funded through the European Commission's ERA-NET Plus procedure enabling a true cooperation based on National agencies from both Europe and the USA and complemented by European Commission funding.

The FHWA Exploratory research programme is linked to the Forever Open Road programme, and many European Institutes attend the TRB conference, as do FEHRL.

For future international cooperation, the FHWA envisage a two phase approach, initially on Policy and Planning (e.g. with the Highways Agency), followed by engineering activities.

New York City is a member of a group of large cities (including London) that face similar transport issues.

There is a role for FEHRL to play in developing the links between itself and its members (and associate members) and the FHWA and others in the USA. This is likely to be more effective than if undertaken by individual institutes, although it is recognised that some bilateral links already exist.

One potential opportunity could be secondments to FHWA or possibly LTRC, and vice versa.

8 RECOMMENDATIONS

Feedback from the participants on the tour was overwhelmingly positive, and future tours are to be encouraged.

In addition to the general collaboration opportunities outlined in the previous section, there are a number of research opportunities that could be explored, including:

- One issue that was raised several times was that current climate models are very broad scale, and therefore imposing on parts of a State or city is a very broad brush approach.
- Getting better rainfall data is a research requirement, and improving rainfall models, which are far less consistent than temperature models.
- While coastal roads seem to be more of an issue in the USA (and possibly Australia) than Europe, landslides and particularly flooding are common to both. Further studies on bearing capacities of roads after inundation and subsequent remediation seem to be a shared research area. The effect of changing climate on pavement life / residual life would also be worth exploring. Related studies have been undertaken in Australia to address this issue, see Austroads Impact of Climate Change on Road Performance (2010) for further information[11].

11 This project produced software that provides climate change information from 1960 to 2099. It identifies the impacts of the mean, minimum and maximum daily temperatures and rainfall estimates on pavement deterioration and pavement performance

Databases and data fusion might be one area where Europe can help, for example the 9,000 databases recorded within Oregon DoT, could be slimmed down. There may be good organisational practices for rationalisation of information. TRL has trialled incorporating RFID Tags in pavements on the Highways Agency network detailing pavement construction.

It was felt that the Pilot Projects were comprehensive, and undertaken on a bigger scale in the USA in that they covered all infrastructure assets, not just, e.g. bridge decks. The concept has been to engage widely and do something different; a similar programme could be undertaken in Europe but would need EU or pan-nation funding.

Additionally, consideration of the opportunities to use the steps in the frameworks developed, and integrate these into current planning processes within other countries could be undertaken.

Further work on assessing changes to standards to accommodate climate change could be considered, as well as identifying materials that are cost effective and do not deteriorate as rapidly due to climate change events, and equally reduce greenhouse gas emissions in their manufacturing, are potential areas of further research.

9 ACKNOWLEDGEMENTS

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Special thanks go to the organisations visited on the tour for the information shared, including provision of presentation materials that have been used in preparing this report. Particular thanks go to Debra Elson of FHWA, Adam Freed in NYC, Jeff Perlman of NJTPA and Skip Paul of LTRC.

APPENDIX A
COUNTRIES AND ORGANISATIONS REPRESENTED

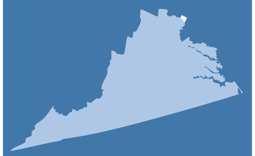
Representative(s)	Country/Organisation
STEVE **PHILLIPS**	Europe/FEHRL
MARKUS **AUERBACH** JURGEN **KRIEGER**	Germany/BASt
KARMEN FIFER **BIZJAK**	Slovenia/ZAG
AVINOAM **AVNON**	Israel/INRC
MICHAEL **LARSEN**	Denmark/DRD
CAROLINE **EVANS**	Australia/ARRB Group
MARTIN **LAMB**	United Kingdom/TRL
GORDANA **PETKOVIC** MORTEN **RANNEM**	Norway/NPRA
GUNILLA **FRANZÉN**	Sweden/VTI
FERHAT **HAMMOUM**	France/IFSTTAR
BUTCH **WLASCHIN**	USA/FHWA

APPENDIX B PRESENTATIONS

PRESENTATIONS FROM THE SCANNING TOUR, AS WELL AS **AGENDA DETAILS** AND **PICTURES** ARE AVAILABLE ON THE **FEHRL FILE ZONE** AT:

http://www.fehrl.org/index.php?m=32&id_directory=7121

APPENDIX C
INFORMATION ON ORGANISATIONS VISITED

STATE	INSTITUTE	KEY PRESENTATIONS/TOPICS/VISITS
Virginia 	Turner-Fairbank Highway Research Centre	• Vulnerability of infrastructure – Gulf Coast 2 Study, Vulnerability pilots, Climate effects study FTA pilots and programs • Adaptation issues and products – Bonner Bridge study, Katrina/Ivan Technical Assistance, Infrastructure needs and approaches • Research efforts – NCHRP 20-83(05), IRT Collaborative Efforts, Climate Change projects • Laboratory tours – Accelerated Load Facility, Aerodynamics, Hydraulics • Policy activities – Adaptation Funding Memo, USACOE Sea Level Rise Policy Memo
New York 	New York City Administration – Mayor's Office of Long-term Planning and Sustainability	• An overview of New York City specific climate change projections, tools to help entities identify climate vulnerabilities and develop adaptation strategies, and recommendations on how to foster an effective climate resilience program.
New Jersey 	North Jersey Transport Planning Authority	• Keynote Speaker – Mitch Erickson, US Department of Homeland Security, Topic: Technology and Infrastructure Resiliency – Transportation Considerations • Special Presentation – Jeffrey Perlman, NJTPA Topic: Climate Change and Infrastructure Vulnerability Assessment in New Jersey • FEHRL Panel Discussion – Status of European Climate Adaptation Work • NJ/NY Panel Discussion – Update on Regional Climate Adaptation Activities
Louisiana 	Louisiana Transport Research Centre	• Submerged road research • I-10 Twin Spans Bridges • Hurricane Generated Wave Loading on Coastal bridges • Evacuation planning, improvements and studies • Elevation and subsidence studies of levees and roads • Considerations for climate change adaptation - Coastal Protection and Restoration Authority of Louisiana • Hurricane and storm damage risk reduction plans • John James Audubon Bridge and field visit

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