UNDERSTANDING RISK AND RESILIENT INFRASTRUCTURE INVESTMENT

http://dx.doi.org/10.12774/eod_tg.july2016.gallegolopezessex3

First published July \ 2016

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1. THE IMPORTANCE OF UNDERSTANDING CLIMATE AND DISASTER RISKS

1.1 INTRODUCTION

Infrastructure will be affected by environmental and climate risks, including disasters. When planning investment, these climate and disaster risks need to be understood over the **full lifespan** of the infrastructure. Moreover, the impact and interactions of the structure in wider infrastructure systems needs to be reviewed with a resilience lens, and decision making harmonised with related strategic and spatial planning decisions reflecting broader societal needs. These requirements relate not just to new structures, but also to maintenance, upgrade and management of existing infrastructure.

Crucially this understanding depends on the availability of risk information (including knowledge of its accuracy and uncertainty) and a clear interpretation of these risks to inform the infrastructure investment decision.

1.2 WHY AN UNDERSTANDING OF RISKS IS NOW CRUCIAL FOR INFRASTRUCTURE INVESTMENT DECISIONS

Infrastructure decisions must be informed by an understanding of the likely frequency and magnitude of climate events and how they are likely to change in the future. It is important to try to understand what the possible future changes might be – be that unpredictable disasters, slow onset impacts or reoccurring seasonal events. This requires an understanding of climate and disaster risk, and an understanding of current weather patterns. For example, what is the natural variability of rainfall (or lack of rainfall) in a location, and how is this affected by phenomena such as El Niño? It is this baseline upon which climate and disaster risks should be then considered (Climate: observations, projections and impacts[1], UK Met Office, 2011).

Climate change models predict significant changes worldwide in temperature, precipitation (rainfall) patterns, storm surges, increases in sudden and catastrophic weather events, and in sea level rise. How these changes impact a particular place will depend on weather systems and topography. This will result in different decisions for the design, operation, maintenance and upgrading/retrofitting of infrastructure in different locations (Disaster Risk Management in the transport sector[2], Moor et al, 2015).

1 www.metoffice.gov.uk/media/pdf/t/r/UK.pdf

2 www.wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2015/07/23/090224b08301eaae/1_0/Rendered/PDF/Disasteroriskooationalocaseostudies.pdf

BOX 1 DEFINING RISK

Disasters are never solely natural. They are the product of how natural incidents interact with aspects such as a lack of preparedness, poor capacity and adaptation, weak resilience, as well as over exposure and vulnerability to hazards. These aspects are, to a great extent, dependent upon development decisions and subsequent human activity. The relationship of these elements can be shown as the following formula:

$$Risk = \frac{Hazard \times Vulnerability \times Exposure}{Capacity}$$

Hazards can generally be classified as 'stress' events (long-term and gradual) or 'shock' events. They can be either known or unknown. Hazards, as the risk formula indicates, do not necessarily lead to disasters, but are only stressors and triggers in the system.

Source: Moor et al (2015) Disaster Risk Management in the Transport Sector.

Thus, addressing the resilience of infrastructure requires an understanding of risks that are complex, uncertain and unpredictable. For this reason resilience should be considered early in the project cycle *before* any preferred engineering solution is considered. Such a *resilience-led* approach will have the following characteristics:

- **Accepting that failure will most likely occur.** Acknowledgement that failure will most likely occur at some point is not the traditional basis for infrastructure planning and design, but it will result in widening the range of solutions that are considered. Accepting that the risk estimates that inform infrastructure selection and design are increasingly uncertain, means a 'failsafe' design is no longer always possible. This generally means accepting that not all risks can be designed out
- **Thinking through the consequences of failure and subsequent recovery.** Accepting that engineering design will increasingly not be able to fully address the impacts of disaster and climate risks, means that climate mitigation and adaptation and disaster preparedness should be considered when infrastructure is planned in the first place.
- **Appreciate how infrastructure behaves as part of wider systems, and is linked to livelihood impacts.** An understanding of how a disaster will impact on a specific piece of infrastructure, *as well as* the wider infrastructure system is needed. Understanding how design is linked to operations in the case of future climate or disaster events should reduce the possibility of cascading failures affecting entire infrastructure systems, as well as wider community and livelihood resilience. This means also appreciating how different individuals, households and communities have different vulnerability, as part of the infrastructure design (see Gallego-Lopez and Essex, 2016c).

1.3 UNDERSTANDING HOW DISASTER RISKS AFFECT INFRASTRUCTURE

An assessment of disaster risks should address the following observations:

(1) That infrastructure rarely operates in isolation. Infrastructure resilience (or failure) can affect the resilience of:

- other infrastructure as part of an infrastructure system (e.g. a bridge functions as part of a road network);
- other infrastructure systems (e.g. electric pumps used in water distribution systems);
- communities, livelihoods and jobs as well as the national economy.

(2) **Potential impacts are often not predicted or understood.** This is partly due to the way infrastructure interacts with wider infrastructure systems and society but also because it is hard to predict the likely impacts of unexpected extreme shocks. This means a reliance on traditional risk analysis techniques often oversimplifies risks or ignores issues. So, traditional risk analysis may understate the risks that should be considered.

Therefore, although risk assessment has been part of traditional engineering design, this has generally been addressed by increasing the 'factor of safety'. This increases robustness but tends to increase the strength of individual elements rather than consider how it impacts on other infrastructure and livelihoods. Such an approach to risk can result in designs lacking flexibility and can result in infrastructure that lacks resilience to unforeseen shocks or stresses (Adapted from Park et al, 2013, cited in Moor et al, 2015).

1.4 UNDERSTANDING HOW CLIMATE RISKS AFFECT INFRASTRUCTURE

Much has been written about climate resilience and climate adaptation in general, but far less on how risks need to be considered differently. (Adaptation to Climate Change in Water, Sanitation and Hygiene[3], ODI, 2014).

Climate change requires different approaches - that assess risks earlier, based on better risk information. Risks need to be considered in a more strategic and interdisciplinary way. This is reflected in the new strategic approach being taken in the UK, as one of the first countries legislating for risk-based approach to climate change. The Climate Change Act (2008) requires a climate change risk assessment every five years to better understand climate risks and what effects they might have on the economy, environment and society (UK Climate Change Risk Assessment[4], DEFRA, 2012).

Similarly, climate related risk management should be at the heart of development planning and infrastructure delivery. However, technical, operational, information and institutional barriers still limit such risk-informed decision-making. Some risk assessments are ignored by decision-makers because the results are difficult to interpret (CDKN, 2014). In an interview with Evidence on Demand for this research in 2016, Mo Hamza, Professor of Risk Management and Societal Safety at Lund University in Sweden, highlighted the current gap in translating scientific climate change information through risk modelling to inform strategic and spatial (infrastructure and planning) decisions. Bridging this gap requires key organisations to translate climatology and hydrological information into a form that can be used for practitioners and decision-makers, such as the UK Met Office. This is discussed further in Section 3 below.

3 www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8858.pdf
4 www.gov.uk/government/uploads/system/uploads/attachment_data/file/69487/pb13698-climate-risk-assessment.pdf

2. CURRENT SITUATION: INVESTMENT DECISIONS NEED A BETTER UNDERSTANDING OF RISK

2.1 ADDRESSING UNCERTAINTY REQUIRES BETTER KNOWLEDGE

The Evidence on Demand Topic Guide on decision making under uncertainty[5] (Ranger, 2013) is highly relevant to the resilience of infrastructure. It sets out how development interventions can be better designed to enhance climate resilience. It concludes that climate change will impact long-term outcomes, requiring adaptation as well as mitigation. This requires:

- **more flexible and progressive strategies** for development programming; and
- **a longer-term approach** for infrastructure investment, design and risk management.

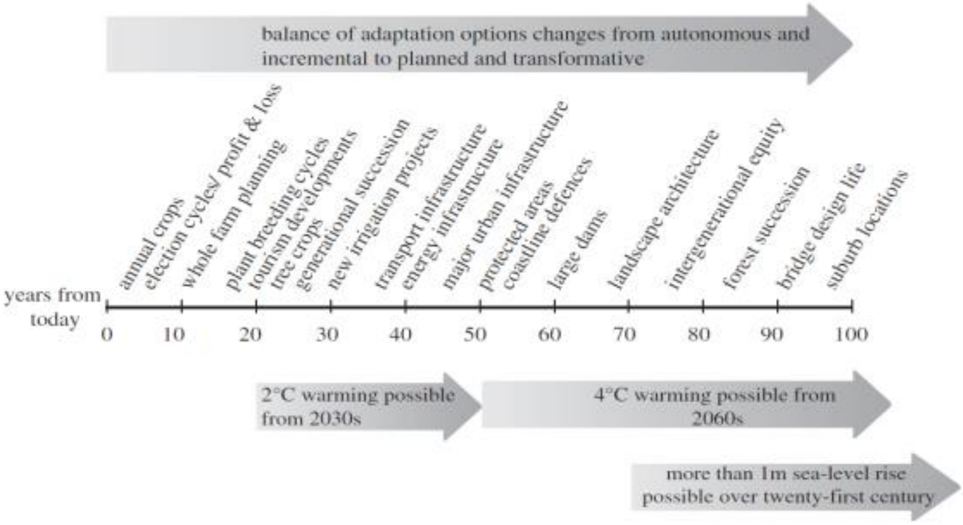
Ranger notes that this is not the way most projects are economically evaluated now – assessments generally only consider impacts over the short time (3-5 years) considered for economic return on investment (ROI). This approach is probably locking-in greater and difficult-to-reverse risks which will occur in the future. For example, mismanaged urbanisation continues to overexploit the natural environment and does not tackle rising water demand.

Better management of climate risks requires a shift to proactive, long-term planning. Ranger gives the example of the Thames Barrier in London, which was only built after 300 people died after flooding in 1953. The Met Office took part in the Thames Estuary 2100 research project[6] which explored alternatives based on likely sea level rise, to improve decision making for the future resilience of London, which highlighted how significantly future climate risk can affect what is the most appropriate infrastructure investment choice, and how this depends on the time horizon chosen.

2.2 NEED TO BETTER UNDERSTAND CLIMATE RISKS FOR INFRASTRUCTURE

Ranger (2013) says that while future climate risks will always be uncertain[7], climate modelling data should still be quantified to inform infrastructure development. This is vital because of the very long timescales of infrastructure and urban/land planning decisions (see figure below). Because climate risk is significant over the time horizons for long-term investments such as infrastructure and spatial planning, it is central to these decisions. Ranger recommends that climate change should form part of national-level decision-making processes (as well as specific decisions).

5 www.evidenceondemand.info/topic-guideadaptation-decision-making-under-uncertainty
6 www.gov.uk/government/uploads/system/uploads/attachment_data/file/322061/LIT7540_43858f.pdf
7 In part because they depend on the extent to which we limit greenhouse gas emissions in the short and medium term. Therefore the approach should be to invest in infrastructure that reduces climate impacts, as well as that which is adaptable.



Source: Stafford-Smith et al (2011) cited in Ranger (2013).

FIGURE 1 COMPARING THE TIMESCALES OF INTERVENTIONS WITH CLIMATE CHANGE.

However, Ranger notes that inadequate attention is currently given to climate risk in infrastructure decision making. A recent review by the World Bank's Independent Evaluation Group highlighted that there is inadequate guidance and that climate risks are not properly understood or considered by decision makers (see figure below). The evaluation concluded that donors should develop reference guidelines to ensure climate risks are incorporated into project and programme designs, appraisal and implementation. DFID have introduced a set of SMART guidelines, which includes a climate and environment screening process (see Horberry, 2014). However, it is not yet clear if these have led to risk information from climate models changing how investment decisions for long-term (infrastructure and planning) investments are made.

Ranking	Direct risk	Effect on external risk	Effect on indirect or secondary risk
1: High	Large components of the project are subject to climate risks facing a country or region (e.g. infrastructure and agricultural projects located in flood- or drought-prone areas)	The project could have a strong effect on the climate risks to which a country or region is exposed (e.g. development projects that trigger development in dangerous areas)	
2: Medium	Some elements of the project are subject to direct risks, but the risk to the project as a whole is limited or only indirect		The project may have indirect effects on the vulnerability of the country
3: Low	The project is not sensitive to climate risks at all	The project does not (negatively) affect external vulnerability	

FIGURE 2 A RISK SCREENING MATRIX PRESENTED BY RANGER (2013)

To create climate-resilient development pathways, climate risk information (and wider resilience considerations) must be internalised within the frameworks, regulations and price incentives that underpin investment choices, in both the public and private sector. This is not currently the case.

Existing regulations include building standards, engineering standards for new public infrastructure, land-use planning, water efficiency programmes and regulation of utilities companies to ensure they include climate change in their long-term planning.

But such individual decisions will also be framed by long-term infrastructure choices. Therefore, it is crucial that strategic planning includes infrastructure investment decisions, and that both prioritise design which limit future climate impact to sustainable levels – both in general terms (climate-smart development mitigates climate change) as well as ensuring that location- specific risks are addressed over the lifespan for any given infrastructure choice (adaptation).

2.3 STRATEGIC AND SPATIAL PLANNING WILL BE BETTER, AND SAVE MONEY IN THE LONGER-TERM

The International Panel on Climate Change (IPPC) has provided evidence that planning for long-term impacts will ultimately save more lives and be cheaper than just dealing with disasters (and subsequent recovery costs) as they occur. This does not just relate to infrastructure investment but to wider strategic and spatial planning[8]. The following examples illustrate how risks could be avoided by planning for long-term impacts, or invited by not doing so:

- UK government investigations of the vulnerability of towns and coastline (Pitt, 2008) addressed the need to properly defend the coastline from erosion, or accept coastal roll-back and the associated long-term planned relocation, as well as (crucially) not continue to develop in these type of vulnerable locations in the first place; while
- a continued expansion of the built environment in Dhaka into its lowest lying area, previously set aside as flood plain for temporary storage of water (Haque, Grafakos and Huijsman, 2012 cited in Essex and Gallego Lopez, 2014), has increased future disaster risk.

Considering just one aspect, the way climate change increases coastal flood vulnerability worldwide, highlights why infrastructure planning needs to strategically consider the spatial location (as well as nature) of future development. Hansen et al (2016) conclude that "if greenhouse gas emissions continue to grow multi-metre sea level rise would become practically unavoidable, probably within 50–150 years".

This climate modelling has been used to predict coastal flood impacts in selected countries. Work by Hinkel (2014) and Richardson et al (2014) on predicting possible impacts in the 2080s, suggests significant coastal flood risks are likely, with the largest numbers of people affected in China, India, Myanmar, Vietnam and Bangladesh. The greatest percentage of the population exposed is predicted in Myanmar, Vietnam and in the Pacific islands.

8 IPCC (2012): "Actions such as relocating people, changing behaviour, agreeing regulatory frameworks, building institutional capacity or diversifying our markets and supply chains will take time and so we need to think and act ahead."

3. RISK DATA AND INTERPRETATION

3.1 INTRODUCTION

In order to understand risk and resilience, it is important to first know what risk information is already available in a given country and location. A range of resources exists that provide an overview of the overall level of hazards, vulnerabilities, socio-economic conditions, impacts and consequences of climate variability and change around the world. A separate challenge is the ensuring that there is sufficient effort and relevant tools to interpret this risk information and modelling for use in decision making; that is, in addition to availability of risk information, coordination and communication of existing information is also important, but challenging[9]. This is affected by the inevitably large number of major players in the resilience context (and further associated networks and platforms) and because this is a rapidly evolving field.

3.2 DATA SOURCES AND INTERPRETATION

A major challenge is sufficiency of data, and access to this data. One of the biggest constraints to running disaster risk and climate change models in less developed countries is data availability and accuracy. In addition, in the case of climate change data there is, in some places, a need for more localised climate modelling work to be undertaken. But addressing this gap requires more than just the data itself, it needs to be accessible, shared and able to be used – as set out in the box below.

BOX 2 SUFFICIENT RISK INFORMATION NEEDED TO INFORM INFRASTRUCTURE INVESTMENT DECISIONS

CDKN (2014) highlights the need for sufficient risk information to inform decision-making on where to invest, what to insure, where to build and how, and to raise awareness among stakeholders about different components of risk. This needs to give sufficient confidence for decision-makers to take these risks on board.

Example. *In West Africa some models project an increase in drought frequency, while others predict the opposite. This means that the overall (project selection) risk assessment needs to reflect this uncertainty, and include sufficient flexibility to adapt to shifting climate hazard characteristics.*

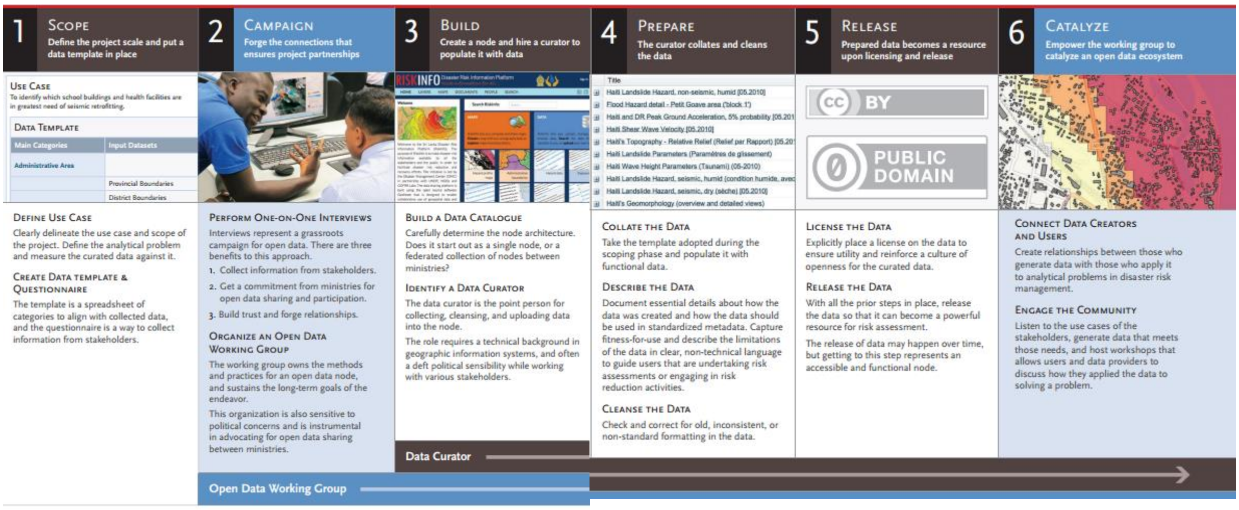
Obstacles to proper assessment of climate and disaster risks in decision-making include:

- **Technical:** lack of data, technological challenges for presentation of information at relevant geographical scales, lack of conceptual clarity, low technical capacity. In addition, the approach must be flexible enough to account for uncertainty, such as in climate change modelling projections.
- **Operational:** risks must be assessed and translated first into recommendations and then into a plan of action. This must also address cost issues. Key aspects include difficulties in interpreting the results and mismatch between scales for different data sources;
- **Institutional:** mismatched/outdated policies, political cycles, mismatched incentives

(Adapted from Risk-informed decision-making: An agenda for improving risk assessments under HFA2[10], CDKN, 2014).

9 https://dfid.blog.gov.uk/2013/04/16/whats-the-problem-with-sharing-knowledge/
10 http://cdkn.org/wp-content/uploads/2014/04/CDKN-Guide_RiskAssessment_FINAL_WEB.pdf

One example of a useful source of **disaster risk information** is the GFDRR's open source and open access software that can quantify risk from natural hazards. This includes the Open Data for Resilience Initiative[11] – Open DRI, highlighted in the figure below. The main objective of Open DRI is to help people in vulnerable regions to better understand the historical and changing risks they face from natural hazards. Open DRI provides technical solutions and assistance through GeoNode[12], a free and open source data sharing platform. Communities from Indonesia, Sri Lanka, Nepal and Haiti have used this initiative to create community mapping projects with millions of individual building footprints.



Source: GFDRR et al, 2014c

FIGURE 3 OPEN DISASTER RISK MANAGEMENT DATA CATALOGUE

As with disaster information, better climate information is required to inform infrastructure investment.

> *"Quality climate observations are essential to reducing losses from extreme events… such as enhancing the design and location of long-lasting infrastructure".* (UNECA, 2014)

For **climate change risk information** there are (still) two significant challenges:

- **Lack of Data.** There is a need to downscale climate models to give better regional and local information, and to improve data on seasonal weather and climate variability in some countries;
- **Insufficient Analysis.** Data needs to be interpreted to inform long-term (infrastructure) investment decisions. As a result infrastructure planning may currently under-estimate climate risks (particularly slow-onset impacts) compared to disaster risks. Addressing this may include developing long-term development scenarios that utilise climate and disaster risk information, and relate these to an understanding not just of the risk context, but how these impact upon the vulnerability of communities and existing infrastructure systems.

These issues are related. While there is a high level of confidence in the processes linking emissions to climate change, much less is known about how climate change will impact locally through changes in rainfall, runoff, groundwater recharge and climate extremes. This reflects not just the

11 https://www.gfdrr.org/sites/gfdrr/files/publication/opendri_fg_web_20140629b_0.pdf
12 http://geonode.org/

challenge to downscaling of climate models and collecting better weather data, but also a challenge of interpretation so as to understand how climate modelling results interface with local conditions. In general, the confidence in climate change projections decreases as their potential utility for making decisions on how to adapt increases (cited in ODI, 2014). This implies that we should prioritise better interpreting and understanding the climate information we already have, while work is ongoing to improve the basic climate information and modelling in any given country.

UNECA's research (Keeping climate impacts at bay: a 6-point strategy for climate-resilient economies in Africa[13], 2014) found that scientific understanding of the (African) climate system is limited and the level of understanding of its complex interactions is relatively poor. Institutional strengthening is needed to fill such knowledge gaps. This is in part being addressed by the World Meteorological Organization, for example, which is extending its basic infrastructure by designating Regional Climate Centres (usually through upgrades to existing centres) to generate and deliver more regionally-focused high-resolution data and prediction products for climate services, especially in support of climate adaptation and risk management.

Other examples of the range of organisations providing support to bridge this knowledge gap are the Norwegian Meteorological Institute and the Asian Disaster Preparedness Centre, which are working to build the capacity of oceanographers and meteorologists in Bangladesh, Myanmar, Pakistan, Philippines, Thailand and Vietnam to utilize wave forecasting as well as storm surge and trajectory modelling for improved early warnings of extreme events that are already affecting these countries (Strengthening capacity in marine forecasting[14], ADPC and MET-Norway, 2015). Similarly there is a strong collaboration between the Met Office and other institutions, including through the DFID-Met Office Climate Science Research Partnership (see Met Office, 2012).

For more information on sources of climate and disaster risk information for a given country or region, refer to the Evidence on Demand Risk Management and Financing resource (Sturgess, 2016b, Part A3: Tools and data sources to feed into multi-hazard risk assessment).

Finally, climate change or disaster risks may not be the most significant impact affecting an area. For example, changes in land cover may have a greater influence on local systems and services than climate change alone. Thus, it is important that information on these other areas of environmental change are also considered and understood.

3.3 INTERPRETING CLIMATE MODELS AND DISASTER RISK INFORMATION

There is often a limited understanding of what impact climate change will have in the long-term, as reflected in various global and downscaled climate models and scenarios. This is particularly the case in developing countries with a lack of capacity and investment in interpreting climate models into information that can be used to inform decision making. However, there are limits to how accurately climate modelling can inform decision making (see Box 3). **A lack of data also makes it harder to take a traditional "fail-safe" engineering approach to infrastructure design. This makes alternative options that draw from the full range of resilience characteristics more attractive** (see Designing Infrastructure Resilience, Gallego-Lopez and Essex, 2016c: section 2.3).

13 http://www.uneca.org/sites/default/files/PublicationFiles/six_point_strategy_eng.pdf
14 http://www.adpc.net/igo/contents/Media/media-news.asp?pid=979#sthash.QGDfjUIT.n9nJob1q.dpbs

Box 3 Climate Modelling Limitations make Resilience led approaches more favourable

Even in the UK, which has good climate data, it is not possible to design to avoid future impacts. For example, UK climate modelling already predicts which areas will be wetter and which drier in the future. In locations predicted to become drier, critical infrastructure is now designed for storms on a return period of once in 500 years. This approach is only possible because the UK has around 200 years of rainfall data. However, this may still be inadequate as climate change is now understood to affect both the frequency and severity of storms. Recent research by the UK Met Office showed a seven-fold increase in risk of winter storms in the UK due to climate change[15].

There are several initiatives in Africa and Asia to better interpret climate models and understand climate risks, as well as improving weather forecasting. Examples of these include:

- ClimDev-Africa[16] supporting the response to climate change in Africa;
- The African Climate Policy Centre[17] which is engaged to help to build resilience of strategic sectors such as agriculture, energy and water and to conduct analytical research to support science informed decision making processes in development; and
- The GFDRR (2015c) has supported early warning systems in about 35 countries, and continues to do through Climate Risk Early Warning Systems CREWS[18]. This will increase investment focused on infrastructure that improves disaster preparedness.
- There are also various climate change vulnerability assessment tools. An example is one for coastal habitats (http://www.ccvatch.com/).

Different risk models have been developed to understand hazard, exposure and vulnerability and therefore the output of the risk model depends on its initial purpose. Some of these can be used to estimate potential economic losses, for instance how many buildings might be damaged in a community given different hazard severities. Prevention Web provides an overview of risk models and modelling tools at Understanding Disaster Risk Modelling (Prevention Web, 2015b), some of which are open access.

Understanding and measuring resilience is widely recognised as complex, requiring a systematic approach. The US Community Resilience Economic Decision Guide for Buildings and Infrastructure Systems[19] (NIST, 2015:p10-13) highlights the need for better infrastructure resilience planning. Different methods for measuring resilience include: the PEOPLES' Framework; the City Resilience Framework developed by Arup with funding from the Rockefeller Foundation; Baseline Resilience Indicators for Communities; the Community and Regional Resilience Institute's Community Resilience System; Communities Advancing Resilience Toolkit (Pfefferbaum *et al*, 2013); and the Resilience Index for Business Recovery (Rose and Krausmann, 2013).

Such an integrated approach that addresses climate and disaster risks together will also improve social protection by transforming, strengthening and protecting household, community assets and livelihoods. This is because climate change and extreme weather events impact both directly and indirectly on human well-being, especially poor households in developing countries (cited "No Regrets" Approach to Decision-Making in a Changing Climate[20], World Resource Institute).

15 https://blog.metoffice.gov.uk/2015/12/11/climate-change-and-weather-caught-in-a-media-storm/
16 http://www.climdev-africa.org/
17 http://www.uneca.org/acpc
18 https://www.gfdrr.org/reducing-risk-weather-extremes
19 http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1197.pdf
20 http://www.wri.org/our-work/project/world-resources-report/no-regrets-approach-decision-making-changing-climate-toward

4. TOOLS AND APPROACHES TO RELATE CLIMATE AND DISASTER RISKS TO INFRASTRUCTURE INVESTMENT

4.1 INTRODUCTION

Once risks have been translated from disaster and climate data sources, they still need to be integrated into the project management cycle to inform country/overall development strategies then programme design, project identification, selection and design of options, through to evaluation and audit, and crucially operation and maintenance (including of existing infrastructure). The key stages considered here are:

1. Planning – across sectors at national, regional and city scales;
2. Investment strategies and decision making;
3. Design options; and
4. Monitoring and Audit.

From a resilience perspective these are considered in this order – though it is recognised that traditional investment often considers *what* investment should be in (such as through a concept or outline design), before assessing *whether* that represents value-for-money, such as through sufficient return on investment. And in many cases the first time resilience is considered is in an audit or risk assessment of some type (e.g. screening of a project or programme). This (traditional) approach is inadequate. Resilience, especially to build long-term climate resilience into infrastructure solutions, requires risks to be understood and reflected in infrastructure choices at an earlier stage.

Climate and disaster risk depends on many location specific physical variables (e.g. distance from and height about the sea and rivers) as well as overall development pathways (e.g. the extent to which development pathways address climate change across the world). This means that these risks are not straightforward, and interface with each other. Thirdly, and critically for infrastructure[21] and wider strategic planning, the risks depend on how far into the future development scenarios plan for. This section considers how these are considered collectively in strategies that guide investment spatially:

- Firstly, in terms of strategic planning, from the country to city/regional scale to ensure that overall development pathways are climate resilient, sustainable and inclusive; and
- Secondly, in terms of the way different infrastructure systems interact with each other (e.g. water, land and energy systems) and impact on livelihoods

[21] Due to the longer lifespan for infrastructure and planning investment decisions.

4.2 PLANNING FOR RESILIENCE – COUNTRY, REGIONAL AND CITY-SCALE STRATEGIES

Effective resilience needs to be planned at different scales such as nationally, regionally and at municipal/city scales. Planning also needs to occur across different infrastructure sectors, and support the wider resilience of communities and society.

This applies to the overall planning of an economy, not just overseas development assistance, which generally forms only a small part of the economy (for example around 2% in Bangladesh), and of which infrastructure investment again is just one part. However, donor policies help countries set new policies and infrastructure is a key factor in determining the overall development pathway of a country, and whether or not it is sustainable and resilient as a result.

A resilience focus requires interdependencies to be considered. These can be:

- between different infrastructure elements (e.g. within a bridge);
- between infrastructure systems (e.g. between water infrastructure and energy infrastructure – such as how a flooding event could shut down an electricity substation); or
- between infrastructure and livelihoods (e.g. how raised road embankments may exacerbate flooding).

These are examples where failure may occur through a domino-effect, where risks are cascaded from one weak point or interface (lack of resilience) and can have knock-on effects to whole communities or and the economy (Infrastructure and systems: past damage and future risk[22], Climate Nexus, 2015). These aspects require resilience to set the context for infrastructure choice and design, so be considered before rather than after infrastructure solutions are chosen.

Such technical understanding of infrastructure interdependencies is critical for cities deciding on strategic investments in infrastructure improvements that will have the greatest payoff in terms of resilience (NAE, 2009). This includes understanding how failures in one infrastructure system can lead to failures in another. For example, the loss of electric power can lead to disruptions in water, transportation, and health care systems. These interdependencies can be, for example, physical linkages, human linkages, cyber linkages, geographic linkages or "logical" linkages.

Resilience requires improved linkages between different sectors (including infrastructure sectors) at a strategic level. CDKN (Risk-informed decision-making: an agenda for improving risk assessments under HFA2[23], 2014) gives examples of collaboration between sectors based on common goals. Many countries have thematic advisory boards that can facilitate such cooperation. For example in Costa Rica the Central American Climate Forum, national university, a regional water board and the Ministry of Agriculture have worked together to share and interpret climate and disaster risk information.

Increasingly the cross-cutting challenge of climate change is being used as a wider platform to articulate and plan for resilience across geographical areas and infrastructure systems. Ranger (2013) notes that adaptation and climate-resilient development are not substitutes – both are needed both to account for climate change in long-lived infrastructure and urban development planning, tackling immediate risks from climate, and preparing for transformational adaptation where necessary. For example, UNDP (2011) notes that "Adapting infrastructure to the risks of climate change within a broader green low emissions climate resilient development strategy not

22 http://climatenexus.org/learn/societal-impacts/infrastructure-and-systems
23 http://cdkn.org/wp-content/uploads/2014/04/CDKN-Guide_RiskAssessment_FINAL_WEB.pdf

only help to reduce the loss of lives, physical damages and interruptions in critical socio-economic services, but it also yields additional benefits from reduced poverty mitigation, more balanced regional development, greater energy security, reduction of greenhouse gas emissions and biodiversity conservation". This should link across sectors, including on cross-cutting issues, and be reflected spatially.

Examples of where this is being done at a country, city-region and city scale are set out below.

- **Ethiopia.**
  - The UK Met Office is helping to improve Ethiopia's hydro-metrological data. Climate resilient infrastructure requires an understanding of the most likely changes in rainfall patterns at a local, national and regional level such that there can be confidence in water security over the next 50 years and beyond. This requires relevant data to be available. Within this support the UK Met office has modelled the Ethiopia climate to understand likely variation in rainfall with climate change (Adebe, 2010) and the wider DFID-Met Office climate Science Research Partnership has provided assistance to improve predictions of climate variability and change (Met Office, 2012).
  - Overall plan to develop climate resilience, as part of the country's overall development strategy FDR Ethiopia, 2011).
- **United States.** Infrastructure in the United States has been highly impacted recently due to the combined impact of sea level rise, more frequent extreme storms, longer droughts and severe floods (e.g. Hurricane Sandy in New York, 2012 and Hurricane Katrina flooding New Orleans in 2005). These failures are associated with limits of infrastructure (threshold effects) being overcome, causing disproportionate damage (cited in Infrastructure and systems: past damage and future risk[24], Climate Nexus, 2015). In 2013, the study US Energy sector vulnerabilities to climate change and extreme weather[25] was released to guide efforts on adaptation measures. Moreover, an interactive map[26] illustrates key climate vulnerabilities per regions. The US National Climate Assessment[27] (2014) summarises the impacts of climate change on the United States, now and in the future. A team of more than 300 experts were involved in the report in order to understand how transport, energy and water infrastructure is being damaged by sea level rise, heavy downpours, and extreme heat; and how damages are projected to increase with continued climate change.
- **El Salvador.** One of the best examples in developing countries is the approach undertaken by El Salvador, a country where almost 90% of the territory is located in high risk areas[28]. Technical assistance to support climate resilient infrastructure in El Salvador[29] (UNDP, 2011), including improving rural drainage systems led to the El Salvador government developing a strategic framework to orient decision-making to increase the climate resilience of public and private infrastructure. This framework aims to integrate emergency, rehabilitation and reconstruction processes that are currently excluded from development plans to enable a shift to a preventative and anticipative approach that accounts for climate adaptation as well as natural resources and biodiversity recovery. This

24 http://climatenexus.org/learn/societal-impacts/infrastructure-and-systems

25 http://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf

26 http://energy.gov/epsa/downloads/climate-change-and-us-energy-sector-regional-vulnerabilities-and-resilience-solutions

27 http://nca2014.globalchange.gov/highlights/report-findings/infrastructure

28 Natural disasters have caused 6,500 deaths since 1972, with an economic cost of $US16 billon. Approximately 60% of the deaths and 87 to 95% the economic losses were related to climatic events.

29 https://www.unops.org/english/News/UNOPS-in-action/Pages/UNOPS-supports-the-Ministry-of-Public-Works-in-El-Salvador-.aspx

emphasises that climate-related decisions should be based on risks rather than observations and adaptable to future realities. (UNDP, 2011).

For sustainability, planning often considers a city-region scale, which is a convenient level to consider economic planning alongside resource sustainability as noted by Scott-Cato (2013) and which should now be reflected in the decision making of engineers (Head, 2009). This could also be an appropriate scale to plan for resilience, and for example the concept of 'regenerative cities' foresees that such cities and their infrastructure create a 'benign, regenerative relationship with the world's ecosystems' (Giradet, 2014). Thus, a truly resilience-focussed approach at a city-scale is likely to involve spatial planning that includes not just a city, but its rural hinterland. Examples of such sub-regional planning for climate resilient development include:

- **Spatial Planning in Bangladesh.** There is now an increasing focus on integration of climate and disaster risks into strategic (national and regional) planning. The Delta Plan in Bangladesh[30] is a leading current initiative that plans to co-create a long-term vision and integrated planning for the delta areas of Bangladesh.
- **Land-use Planning in Rwanda.** There is a national strategy to more evenly spread development across six city-regions, rather than focus on the capital Kigali, which will improve the resilience of the country' economy as a whole (see affect the Green City Framework and Guidelines for Secondary City Development in Rwanda[31]: GGGI, 2014).

Rapid urban development, with increasing concentration of people and assets, is particularly vulnerable to climate and disaster risks. About 90% of people in urban areas in low-income countries live in unsafe and exposed housing. By 2050 urban populations exposed to cyclones and major earthquakes could more than double worldwide[32], largely due to poorly planned and managed urban development[33]. Improved cooperation is required to enhance building codes and integrate best practice into city regulations, land-use planning and investment decisions. This should focus infrastructure investment on improving resilience through improved energy access, water supply and urban drainage systems in particular (Prevention Web, 2015a). Examples of this include:

- **Cities in Vietnam.** Plans to mainstream disaster risk management in Vietnam (GFDRR, 2014a) show engineering measures are not sufficient to tackle disaster risks on their own. This case study highlights that *integrated spatial planning* is needed to counter trends that are driving urban flood risk, such as through optimization of upstream reservoir operation, land subsidence control, and prevention of tidal flooding and rainfall inundation all integrated into spatial development planning of rapidly growing cities. GFDRR support to Vietnam (World Bank, 2015) recommended that infrastructure investments must be linked with wider engagement including spatial planning to control development in hazard prone areas, noting that this is particularly essential in the case of rapidly growing cities.
- **Urban planning in Bangladesh.** The Guidelines for mainstreaming disaster risk reduction into land use planning for upazilas and municipalities in Bangladesh[34] (ADPC, 2013a) aim to establish a common land use planning process at local level and integrate disaster risk information and disaster risk reduction strategies into city planning. Wider guidance produced by the Asian Disaster Preparedness Centre (2013b) in the form of a Disaster Risk

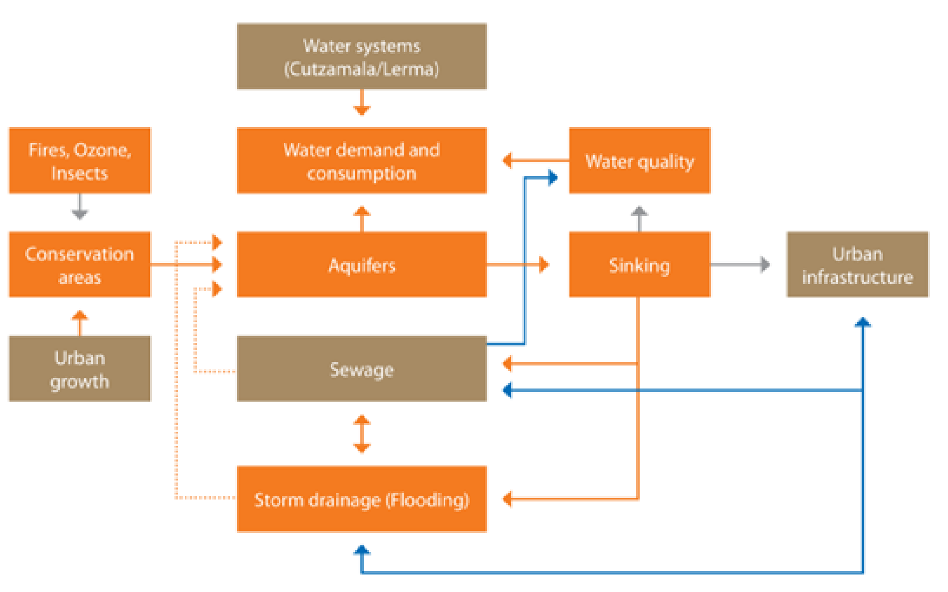
30 http://www.bangladeshdeltaplan2100.org/
31 http://www.greengrowthknowledge.org/sites/default/files/GGGI%20Rwanda%20Fact%20Sheet%20-%20Climate%20Resilient%20Green%20Gities.pdf
32 From 310 million to 680 million exposed to cyclones and from 370 million to 870 million exposed to major earthquakes.
33 http://www.preventionweb.net/risk/poorly-planned-managed-urban-development
34 http://www.adpc.net/igo/category/ID509/doc/2014-y17Gw3-ADPC-Guidelines_Bangladesh.pdf

Management Practitioner's Handbook[35] aims to help DRM practitioners to integrate disaster risk management into urban management.

- The city of **Surat in India** has successfully coordinated an inter-sectoral approach. After suffering severe flooding in 1994 it set up a municipal commissioner to coordinate reconstruction. This recognised the need to improve sewerage, storm water drainage and flood management to reduce likely future impacts. The Chamber of Commerce encouraged residents to return to the city and continue businesses (see Arup, 2014, p.15).
- A case study in **Singapore** assessed how the natural environment can improve urban resilience using GIS-based maps. This highlighted how the 'ecosystem services' provided by the natural environment are vital for sustainability, and proposed methods for optimising the ecosystem services provision within the cities[36].
- Analysis of **Mexico City**'s infrastructure needs demonstrated the need for an integrated, participative, multi-sectoral approach to address climate change risks and deliver long-term sustainable infrastructure resilience. This is set out in the Box 4.

BOX 4 INTERCONNECTIONS IN WATER INFRASTRUCTURE IN MEXICO CITY.

Mexico City's urbanization has seen increases in rainfall, which impacts on infrastructure design. Meanwhile climate change is impacting water security with water availability decreasing by an estimated 10-16%. However, local government is still addressing flooding and water supply as separate problems. This highlights the need to take a multi-sectoral perspective to integrate climate change risks in infrastructure investment and design choices. The figure below highlights how water drainage, water supply and urbanization are interconnected.



Source: UNDP, 2011:p72-79

35 http://www.adpc.net/igo/category/ID409/doc/2013-w06Evi-ADPC-ADPC_DRM_Practitioners_Handbook_-_Urban_Management.pdf

36 https://planet-risk.org/index.php/pr/article/view/169/315

4.3 REPRIORITISING MAINTENANCE AND IMPROVEMENT OF EXISTING INFRASTRUCTURE

Invest in Operation and Maintenance, not just Capital Assets

Infrastructure cannot be resilient if it is poorly maintained. Increasing climate and disaster risk increases the resources, expertise and skills needed to maintain infrastructure. Maintenance also preserves the economic value of infrastructure investment, extending the life of infrastructure into the future. This should be prioritised over provision of new infrastructure through better demand management to manage the infrastructure gap (Cox, 2015). But just shifting to a focus on better maintenance of existing infrastructure is also insufficient. Increasing climate risks (in particular) lead to increasing variability, frequency and extremes of hydro-meteorological risks, as well as slow-onset impacts such as sea level rise. This will mean infrastructure may need to be adapted, which may also change the way it is operated and maintained.

The following table (from Tierney, cited in Bruneau et al, 2003) highlights that despite the engineering and scientific precision focus on the **robustness** of enforced building codes and the quality of construction, resilient infrastructure is also dependent on external factors which may be outside the control of a specific engineering design. The resilience of infrastructure requires a certain degree of **redundancy** (at a system as well as individual infrastructure level). It should also be able to **recover rapidly** after a disaster or repair through good infrastructure and economic planning and operational management systems. This means there must be sufficient **resources** (finances as well human capital, equipment and organisational assets) to not just provide infrastructure and make it work initially but look after it and keep it working thereafter.

Dimension/Quality	Technical	Organizational	Social	Economic
Robustness	Building codes and construction procedures for new and retrofitted structures	Emergency operations planning	Social vulnerability and degree of community preparedness	Extent of regional economic diversification
Redundancy	Capacity for technical substitutions and "work-arounds"	Alternate sites for managing disaster operations	Availability of housing options for disaster victims	Ability to substitute and conserve needed inputs
Resourcefulness	Availability of equipment and materials for restoration and repair	Capacity to improvise, innovate, and expand operations	Capacity to address human needs	Business and industry capacity to improvise
Rapidity	System downtime, restoration time	Time between impact and early recovery	Time to restore lifeline services	Time to regain capacity, lost revenue

Source: Tierney (cited in Bruneau et al.,2003).

TABLE 1 MATRIX OF RESILIENCE QUALITIES FOR INFRASTRUCTURE.

The best maintenance strategies focus on not sustaining the infrastructure itself but the skills and processes responsible for planning, operation and maintenance. This needs to reflect the greater predicted risks in the future, over the full lifetime of infrastructure, as well as how it connects to other infrastructure systems. The way the resilience of existing infrastructure is optimised is often called **asset management**. And the measures addressing the impacts of infrastructure interdependence are also known as infrastructure resilience (Cox, 2015).

Routine and periodic maintenance are key to ensuring infrastructure resilience is sustained through disasters and over its full design life. An example of this is the Mozambican transport network which aimed to strengthen its climate resilience by improving maintenance in ways that address long term changes in precipitation, as set out in the table below (see Box 5).

Similarly, the Transport Research Laboratory (2011) has identified specific measures that can help build resilience into projects to improve the adaptive capacity of transport infrastructure[37]. This includes aspects such as:

- **Understanding future infrastructure use.** The Future Resilient Transport Networks project aims to answer - what will be the nature of the UK transport system in 2050, both in terms of its physical characteristics and its usage, and what will be the shape of the transport network in 2050 that will be most resilient to climate change?
- **Identification of adaptation/measures for existing infrastructure.** Examples include improving the resilience of Nigerian roads to climate impacts, through identifying adaptation measures/actions to reduce the likely damage/disruption due to climate change and cost-effective adaptation of railway earthworks to climate change.
- **Bridging the gap from modelling to engineering design.** Drainage risk models for roads which utilise user costs for different flood severities on different road types and identify the road sections most vulnerable to pluvial flooding.

Box 5 Maintenance remains critical to Infrastructure Resilience

"The largest problems currently facing the road network in Mozambique are overloaded traffic and the lack of maintenance and poor drainage. In the future, the main problems are expected to relate to changes in rainfall as well as changes from temperature, sea level and cyclones. This long-term analysis was based on four climate scenarios. These changes make sufficient maintenance more critical – and a key determinant of climate resilience after initial construction. Without routine maintenance, there is no possibility for a road to meet its design life today, let alone the future climate. The cost of climate change during 2010-2050 is estimated at about $US 600 million (based on 2009 costs). Adaptation measures proposed include:

Design:

- Revised 'design storm' parameters and design flood estimation method for drainage systems/structures.
- Design culverts that limit damage to roads during floods and use spot improvements in high risk areas
- Design gravel/community roads with materials suitable for the climate and topography
- Revised alignments (where needed) to account for future changes including increased rainfall, groundwater, sea level raise, storm surge and related impacts (e.g. flooding and transboundary rivers).

Maintenance:

- Prioritise maintenance and drainage upgrades in areas with highest flood risk
- Increase frequency of drainage maintenance, in relationship to the increased frequency of large storms"

Source: Making transport climate resilient, country report: Mozambique[38] (COWI, 2010).

New Zealand established critical infrastructure institutional arrangements to ensure operational capacity and preparedness to respond if there is a disaster. Regional Engineering Lifeline Groups now work closely with regional emergency management so utility operators can work with others to identify and address interdependences and vulnerabilities to regional scale emergencies. The regional engineering lifeline groups work closely with regional emergency management (APEC,

37 http://www.resilientmobility.com/taking_action/case_studies_and_projects

38 http://www.ppiaf.org/sites/ppiaf.org/files/publication/Mozambique_Making-Transport-Climate-Resilient.pdf

2010). A National Engineering Lifeline Committee consisting of private companies, NGOs, and government agencies was also established in 1999.

4.4 REPRIORITISING INFRASTRUCTURE IN DIFFERENT INFRASTRUCTURE SECTORS

The current global focus on investing heavily in expanding transport networks, primary energy production and resource extraction tends to reduce long-term resilience globally. However, a number of studies suggest that resilience should be reviewed in terms of sector investment both nationally and regionally. Examples of the potential way in which this would transform infrastructure investment in the power, water supply and WASH sectors are set out in Boxes 6 and 7 below.

Box 6 Example - The Overall Cost Impacts of Failing to Prioritise Climate Resilience in the Water and Power Sector (in Africa's Main River Basins)

The Enhancing the Climate Resilience of Africa's Infrastructure: The Power and Water Sectors Study[39] (AFD and World Bank, 2015) focuses on climate change impact on the physical and economic performance of hydropower and irrigation investments in Africa's main river basins. The analysis indicates that failure to integrate climate change in the planning and design of power and water infrastructure could entail, in the driest climate scenarios, losses of hydropower revenues of 5% to 60%: increasing consumer expenditure by up to three times. In the wettest climate scenarios, business as usual infrastructure development could lead to foregone revenues in the range of 15% to 130% of the baseline, if the larger volume of precipitation is not used to expand hydropower production.

Box 7 Example - Targeting Investment to Enhance Resilience in the WASH Sector

Guidance for WASH (water, sanitation and hygiene) response to disaster risks is set out by UNICEF (2015). This provides a good introduction to considering disaster risk reduction in WASH and provides examples of actions for prevention, preparedness and response. In contrast the impacts of climate change on WASH infrastructure resilience is analysed through case study reviews from Malawi, Sierra Leone and Tanzania. These conclude that predicting the impacts on availability and quality of freshwater and water-dependent services and sanitation remain difficult as stated in the Adaptation to climate change in water, sanitation and hygiene assessing risk and appraising options in Africa[40]. For example, although comprehensive data has been collected in Ethiopia on the functionality of water systems, existing levels of climate variability affect the services received to the extent that even in 'covered' communities with functioning infrastructure and robust institutions, households can struggle to meet even minimum (emergency) drinking water needs.

This, therefore, implies a **greater focus on ensuring the reliability and protection of drinking water sources as well as small changes to latrine design** in order to reduce the risks of flooding under current climate variability as a first step towards adopting low cost changes in design or practice (ODI, 2014). As water is predicted to be the main channel through which the impacts of climate change will be felt by people, ecosystems and economies this should be reflected in choices of where to focus infrastructure investment.

Taking such an overall, resilience (wider risk) led approach to the planning and design of infrastructure will change not just way in which currently planned infrastructure is delivered but the different types of infrastructure that are deployed and the way in which this is undertaken.

The need for better coordination across infrastructure systems is also highlighted by research into the likely impacts of climate change on water, sanitation and hygiene by ODI and British Geological Survey in Working Paper 337 (Calow et al, 2011). This summarises current projections of the likely

39 https://openknowledge.worldbank.org/handle/10986/21875
40 http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8858.pdf

impact of climate change on water resources and WASH in Asia, and how this impacts on both policy and practice, as summarised in Table 2 below.

Climate change impacts on water variables and WASH	Policy response and engagement	Operational responses and pro-poor adaptation
1. Climate prediction uncertainty impacts water availability/quality. 2. Likely increased seasonality and higher intensity rainfall impacts river flow, groundwater recharge and water reliability. 3. Increased suspended solids can cause microbiological contamination if WASH infrastructure floods water sources. Sea level rise increases salt water in freshwater aquifers. 4. Monitor to understand quantity, quality, distribution and water resource reliability. 5. Climate impacts livelihoods in other ways (urbanisation, changing consumption, pollution, etc.). 6. Discuss water security. Water scarcity affected by access, entitlements and equity.	1. Integrate adaptation into all climate change policy. UNFCCC leads adaptation globally. 2. Greater focus on vulnerability causes. Plan beyond current needs so flexible, limit maladaptation. 3. National Adaptation Programmes of Action (NAPAs) raise awareness but need to mainstream wider policy 4. Make plans climate resilient: assess vulnerability, scenario plans, adaptive management, community and ecosystem based management. 5. Engage stakeholders: hazard and adaptation assessments, vulnerability, share climate knowledge for decision making/climate proof investment.	1. Climate screening of investments. 2. Promote pro-poor adaptation: e.g. water safety planning, frameworks such as CRiSTAL[41] and Sustainable Livelihoods Approach[42]. 3. Mainstream lessons learnt including broad livelihood and equity improvement, reduce vulnerability, political support. 4. Approach to choose technology should include uncertainty: appropriate to local conditions, focus on reliability of sources

Source: Adapted from Calow et al, 2011

TABLE 2 HOW CLIMATE WILL IMPACT WATER RESOURCE AND WASH INFRASTRUCTURE IN ASIA

4.5 TARGETING NEW INFRASTRUCTURE INVESTMENT TO ENHANCE RESILIENCE

Three different approaches have been identified to prioritise investment in infrastructure to ensure that it is resilient (and sustainable[43]).

[41] CRiSTAL (Community-based Risk Screening Tool for Adaptation and Livelihoods) is a project planning tool to support climate adaptation activities (http://www.iisd.org/cristaltool/).

[42] The Sustainable Livelihoods Framework comprises the framework and a set of guiding principles that consider resilience as a component to address/overcome poverty. It is now hosted by IFAD.

[43] As noted elsewhere for a whole development pathway to be one that delivers long-term sustainability and resilience then this must apply to all capital investments. This means that infrastructure cannot choose between being disaster or climate resilient, and in that whether it is climate smart because it reduces carbon emissions of livelihoods/communities, or whether it helps wider society adapt to climate change: both are required throughout.

1. **Critical/national infrastructure directs sustainable and resilient investment/ development.**

This requires climate data to be identified, available and interpreted so that it is applied to all investment decisions (public, private or donor-led) as part of strategic and spatial planning that ensures infrastructure planning directs development to be sustainable and resilient rather than locking-in climate and disaster risk.

2. **(Community) Infrastructure Investment that enhances community resilience.**

Another approach to investing in resilient infrastructure is to **establish a specific fund to focus on infrastructure investment that enhances wider (community, livelihood, society) resilience**. One example of this is CRIDF which directs funding towards appropriate types of community-scale infrastructure investment, and then screens these to check investment is appropriate (see section below):

- The Climate Resilient Infrastructure Development Facility[44] (CRIDF) in Southern Africa (Malawi, Mozambique, South Africa, Tanzania, Zambia, and Zimbabwe) supports pre-planned climate resilient infrastructure projects by providing finance for small-scale infrastructure, access to finance for larger projects, or technical and engineering support. CRIDF also provides technical assistance to build climate resilience into the scope, design and operation of planned infrastructure. CRIDF facilitates the implementation of transboundary Integrated Water Resources Management plans that mainstream climate resilience into water resources management and monitoring. CRIDF for example is implementing small scale water infrastructure in the Kavango Zambezi Transfrontier Conservation Area (KAZA)[45] and it is testing a number of concepts such as how to enhance resilience in a zone of high and increasing variability, assessing and re-thinking the boundaries between public and private roles in tackling climate change.

3. **Enhancing the resilience of climate vulnerable locations.**

The third approach that has been identified is to target investment particularly on areas most at risk from climate change. Many suchcountries have been identified by the IPCC (2013), such as small island states in the Pacific Ocean, as having a high adaptation deficit[46]:

- Even without climate change, Pacific islands are already massively affected by existing climate variability and extreme events. They are particularly vulnerable to future changes. The ADB Climate Change Adaptation Program (CLIMAP) supports these island states to enhance their adaptive capacities and resilience to climate variability, change and extreme events. This focuses on embedding a risk-led approach to climate proof during the design stage of infrastructure projects. (Climate Proofing: a Risk Based Approach to Adaptation[47] ADB, 2005:p117).

In a similar way investment could also be targeted in other locations that are particularly vulnerable to climate change, such as Bangladesh[48].

44 http://www.southsouthnorth.org/wp-content/uploads/CRIDF-Expanded-Introduction.pdf
45 http://www.cridf.com/#!projects/c1vw1
46 This is identified as countries where "the gap between the current state of a system and a state that minimizes adverse impacts from existing climate conditions and variability".
47 http://www.adb.org/sites/default/files/publication/28796/climate-proofing.pdf
48 http://reliefweb.int/map/world/world-climate-change-vulnerability-index-2014.

4.6 ADAPTING INVESTMENT DECISION TOOLS TO INCLUDE FOR RESILIENCE (AND SUSTAINABILITY)

As well as prioritising what type of infrastructure investment to focus upon, there is still a need to somehow internalise risk and resilience into economic decision making. Currently infrastructure investment is generally assessed considering its economic return on investment. However, this does not usually internalise environmental or social impacts, or benefits.

Also, the return period for investment is typically shorter than the overall infrastructure design life, which is less than the actual life of infrastructure, over which climate and disaster risks should be considered. This means that currently infrastructure investment is not driven by, and may not seriously consider, climate and disaster risks. The traditional approach has been an assumption that negative environmental and social factors can be addressed at the design and construction stages (as reflected in environmental and social impact assessments). However, for resilient (and sustainable) development a different approach is required, where resilience is planned strategically, and then reflected in investment decisions and subsequent design choices.

It is worth noting here that cost-benefit analysis (CBA) generally only really factors in risk and probability through sensitivity analysis, and even this tends mainly to focus on cost and demand/performance sensitivity as opposed to environmental, social or risk related issues. Many donors, including DFID, do not include risk analysis within their cost benefit analysis methodologies. This suggests it is worth reviewing the way that CBAs are used to identify ways that resilience/risk impacts can feed into decision making.

4.7 CONSIDERING RESILIENCE OPTIONS AND INFRASTRUCTURE SYSTEMS

In some cases it may be more appropriate to invest in natural 'green infrastructure' as opposed to engineered infrastructure. For example in Gibson, Canada public sector asset management has also used natural assets alongside engineering infrastructure to enhance resilience such as flood control through reducing surface runoff (Machado, 2015). Rural land management is also highlighted as vital to improving flood resilience in the UK by Pitt (2008).

This is discussed in more detail in the Evidence on Demand Designing Infrastructure Resilience resource (Gallego-Lopez and Essex, 2016c).

4.8 MONITORING AND AUDIT OF INFRASTRUCTURE INVESTMENTS AND SOLUTIONS: CLIMATE/RESILIENCE SCREENING

Various countries, donors and programmes use screening tools to assess investment decisions. However, this approach tends to follow and comment on investment decisions, rather than precede and set the context for taking them. This could be viewed as the equivalent of an 'environmental impact assessment' focused on climate, disaster and resilience aspects. Therefore, while it is a useful tool to review the climate and disaster risk information associated with an investment decision, project or programme design it is not sufficient on its own to ensure disaster and climate risks have been reflected in investment decisions or resilience embedded into infrastructure design, as set out in the sections above, and in the separate Evidence on Demand Designing Infrastructure Resilience resource (Gallego-Lopez and Essex, 2016c) respectively.

The following examples include tools at both the project and programme level:

- **Screen which projects are resilient.** The Climate Resilient Infrastructure Development Facility (CRIDF) is a DFID funded[49] initiative that recently set out a screening (and pre-screening) process to assess the resilience of individual projects. It was based on the EBRD two stage (resilience) screening process. Firstly, screening is sector-based and, secondly, country criteria are used to flag risks and other strategic aspects. The aim was for replicability and the potential for transformative change. It is a similar approach to where screening is incorporated into an SEA, such as for the Caribbean Development Bank. The screening tests to audit which projects are resilient, and which are not.
- **Audit investments.** DFID have a process to similarly audit its investments, to review the extent to which climate and wider environment risks have been considered (Horberry, 2014).
- **Audit existing infrastructure/infrastructure systems.** ODI (2014) proposed a relatively simple approach to risk screening that could be applied by project managers and implementers to identify and plan the mitigation of risk in WASH infrastructure.
    - Firstly, a national level risk assessment to WASH that can be set out as "yellow-green-amber" scorecards using documented indicators of vulnerability and expert's judgement.
    - Secondly determine to what extent a WASH programme addresses key risks and vulnerabilities, again using a simple scoring system, documented evidence and expert judgement.
    - Finally, the use of cost-benefit analysis CBA[50] to prioritise adaptation measures which provides a more secure and transparent basis for investment decision making rather than 'pure judgement'. Nonetheless, robust CBA requires reasonable data on what would happen to WASH interventions with and without adaptation (Source Adaptation to climate change in water, sanitation and hygiene assessing risk and appraising options in Africa[51]).
- **Identify where further climate analysis is required.** ADB and AfDB Infrastructure Resilience Screening Tool (used by internal staff users). This consists of a climate safeguard system that includes an Infrastructure Resilience Screening Tool which should take place at concept note stage. The purpose of this tool is *not about funding*[52]; it is described as a software manual scorecard that determines whether a project has high, medium or low sensitivity to climate and environment issues. The tool is used to identify where climate analysis is necessary. It is not clear to what extent it filters out projects/investment decisions that do not enhance resilience. Or whether this is an interim tool, to be replaced by full integration of resilience in investment decisions at some stage. It is not clear in what way conducting an environmental impact assessment (EIA) is a sufficient approach to considering the resilience of medium sensitivity projects.

49 http://www.southsouthnorth.org/climate-resilient-infrastructure-development-facility-cridf/.
50 Note this relates to investment decision making as described in the section above. Cost benefit analysis itself rarely considers climate or disaster risks.
51 http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8858.pdf
52 So appears to be more of a risk audit or screening tool, as opposed to being integrated into infrastructure investment decisions.

If the project is high-medium sensitivity and adaptation measures are necessary, the project will still happen but needs detailed design to overcome this sensitivity (e.g. for coastal design the measure could be to change the route, as the one selected is highly vulnerable to floods):

- High sensitivity – then a detailed climate analysis is necessary, further analysis on long term projection of water, temperature, etc.;
- Medium sensitivity – an EIA is required; and
- Low or no sensitivity – proceed with detailed design.

Other examples of evaluating infrastructure to prioritize investments aimed at improving climate resilience are set out by the GFDRR et al (2014b).

4.9 CONCLUSION

In conclusion, infrastructure investment can be better planned and decisions made in ways that reduce physical exposure and vulnerability. However, this requires different approaches that have greater investment at the very early stages to start with an understanding of risk, are resilience-led and performance-based. This will result in a wider range of solutions being considered before investment, let alone appropriate design and construction occurs.

This will also need to ensure that infrastructure investment sits within country strategies, regional and city strategies and sector strategies that are both resilient and environmentally sustainable. As a result there will be a shift in funding between different infrastructure types, towards community infrastructure, and in favour of enhancing resilience of communities and existing infrastructure rather than providing new build projects based on economic investment rationale alone.

From a practical point of view this means donors/IFIs will need to spend more to bring a project to a bankable stage as greater modelling information and interpretation will be needed. This is required to properly understand which solutions enhance resilience and which may have an unintended effect of increasing infrastructure/community vulnerability to current and future disaster and climate risks.

RECOMMENDED SOURCES

"Infrastructure plays an important role in the development of countries. In many developing countries, evolving infrastructure can be particularly climate-sensitive and therefore highly vulnerable to the destruction that occurs due to natural disasters"

Paving the Way for Climate-Resilience Infrastructure Guidance for Practitioners and Planners

How the material could be used

This report presents an overview of the presentations made at the international conference on 'Strategies for Adapting Public and Private Infrastructure to Climate Change', held in El Salvador in 2010. This conference aimed to be a starting point to define the conceptual framework for a national and regional strategy to increase climate resilience of infrastructure in El Salvador, however it is noted that could be applicable for other countries and regions. The report describes structural and non-structural measures than need to be taken into account and practical examples taken from other countries such as Mexico.

Why this is a good resource

Contains useful technical presentations to set up the process to integrate climate change risks and opportunities into the design of infrastructure and key principles for making infrastructure more resilient.

Length and level of detail

Fairly long and detailed paper (148 pages) but does not require prior knowledge of the subject.

How to reference

UNDP, (2011). Paving the Way for Climate-Resilience Infrastructure Guidance for Practitioners and Planners. Available from: http://www.uncclearn.org/sites/default/files/inventory/undp_paving_the_way.pdf

Links to further material

- Asian Development Bank, (2005). Climate Proofing: A Risk-based Approach to Adaptation. Pacific Studies Series. Available from http://www.adb.org/Documents/Reports/Climate-Proofing/main-report.asp.

Was this resource useful?

Please contact us with comments on how you have used this resource or if you have further suggestions/questions. Please rate this material.

Keywords [tags]

Climate resilience, risk-informed decision making, infrastructure development, risk assessment and management, climate proofing

City Resilient Framework

How the material could be used

This framework provides cities with a tool to understand resilience and shape urban planning, practice and investment. The framework is based on three other documented research reports which include 14 city case studies and also good examples of resilience initiatives in different countries/cities.

Why this is a good resource

This framework establishes four main aspects of resilience - health and wellbeing, economy and society, leadership and strategy and systems and services - as well as 12 indicators by which resilience can be understood.

Length and level of detail

Main report/framework is fairly concise and easy to read (24 pages long). Previously to this, the Resilient City Index was launched to provide cities with a robust, holistic and accessible basis for assessment. This framework provides the foundation for the Index, defining its structure; the categories, the indicators and sub-indicators.

How to reference

Arup and Rockefeller Foundation (2014). City Resilient Framework. Available from: http://publications.arup.com/Publications/C/City_Resilience_Framework.aspx

Links to further material

» Toolkit for Resilient Cities available from http://w3.siemens.com/topics/global/en/intelligent-infrastructure/pages/resilience.aspx and Executive Summary available from https://w3.siemens.com/topics/global/en/sustainable-cities/resilience/Documents/pdf/Toolkit_for_Resilient_Cities_Summary.pdf

» City Resilience in Africa: a Ten Essentials Pilot http://www.droughtmanagement.info/literature/UNISDR_city_resilience_africa_2012.pdf

Was this resource useful?

Please contact us with comments on how you have used this resource or if you have further suggestions/questions. Please rate this material. 👍

Keywords [tags]

Urban resilience, resilience measurement, resilience indicators, resilience principles, resilience index

Building Regulation for Resilience: Managing Risk for Safer Cities

> **"Building and land use regulation has proven a remarkably powerful tool for increasing people's safety and resilience and limiting the risk that they face, including both the risk of large, rapid-onset events such as earthquakes or cyclones, and the risk of more contained but still deadly events such as fire or spontaneous building collapse"**

How the material could be used

This report can assist policy makers, government, donor and private sector in leveraging good practices in implementing and enforcing building regulations in order to reduce chronic risk and disaster risk in developing countries that are starting out on the path to effective reform and long-term resilience.

Why this is a good resource

This recently established programme aim to bridge the gap between implementation and regulatory framework systems with a special focus on vulnerable settlements in low and middle income countries.

Length and level of detail

Comprehensive report (136 pages) providing practical recommendations and presenting key lessons, experiences and challenges to progress in building regulatory capacity for DRR.

How to reference

World Bank Group and GFDRR, (2016). Building Regulation for Resilience: Managing the Risks for Safer Cities. Available from: https://www.gfdrr.org/urban-risk-resilience-%E2%80%93-building-safer-cities

Links to further material

» Philippines Forum on Safe and Resilient Infrastructure in 2013. Available from https://www.gfdrr.org/sites/default/files/publication/WB%202014%20Philippines%20Forum%20on%20Safe%20and%20Resilient%20Infrastructure.pdf

Was this resource useful?

Please contact us with comments on how you have used this resource or if you have further suggestions/questions. Please rate this material. 👍

Keywords [tags]

Preparedness, Resilience Cities, Building codes, land use regulations, disaster risk reduction.

Topic Guide Adaptation: Decision making under Uncertainty

How the material could be used

This guide addresses challenges face by uncertain future climate, which has real implications on development. This report highlights different concepts and tools dealing with the changing and uncertain climate in designing and implementing development interventions. This also includes methods for quantitative options appraisal.

Why this is a good resource

This guide provides an overview of how to manage the changing and uncertain climate in development decisions today. It is a relevant source for development professionals, including DFID staff, in order to make decisions under uncertainty and where to look for further information.

Length and level of detail

This is a medium length (86 pages) and not comprehensive manual but aims to provide sufficient information to development professionals for both experts and non-expert on climate change

How to reference

Ranger, N. (2013). Topic Guide. Adaptation: Decision making under uncertainty. Evidence on Demand, UK 86 pp. Available from: http://dx.doi.org/10.12774/eod_tg02.june2013.ranger

Links to further material

Risk-informed decision-making: An agenda for improving risk assessments under HFA2 (2014). Available from: http://cdkn.org/wp-content/uploads/2014/04/CDKN-Guide_RiskAssessment_FINAL_WEB.pdf

Was this resource useful?

Please contact us with comments on how you have used this resource or if you have further suggestions/questions. Please rate this material.

Keywords [tags]

Climate change, decision making, decision support tools, development planning, programme design, resilience, risk assessment

REFERENCES AND ACRONYMS

Please refer to the consolidated reference list for sources and acronyms used in the infrastructure resilience resources at http://dx.doi.org/10.12774/eod_tg.july2016.gallegolopezessex4