A GUIDE FOR USAID PROJECT MANAGERS

FLOOD MANAGEMENT

INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

NOVEMBER 2015
ACKNOWLEDGMENTS
This guide was developed for the United States Agency for International Development (USAID) by AECOM as part of a series of sector specific climate change adaptation manuals prepared for the USAID-funded Global Climate Change, Adaptation, and Infrastructure Issues Knowledge Management Support Project.

COVER PHOTOS
The cover photo shows workers who are constructing a diversion channel to prevent future erosion in an effort to create greater resiliency in the surrounding community from climate change impacts, such as increased flooding (USAID AFGHANISTAN ALP). Inside photo shows view of Wadhi Daghabaj Dam, a component of the Flood Control Program in Jeddah, Saudi Arabia. Designed to prevent flooding by channelling flood waters away from Jeddah.

DISCLAIMER
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GLOBAL CLIMATE CHANGE, ADAPTATION, AND INFRASTRUCTURE ISSUES KNOWLEDGE MANAGEMENT SUPPORT

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NOVEMBER 2015
A METHODOLOGY FOR INCORPORATING CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE PLANNING AND DESIGN

FLOOD MANAGEMENT
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KEY TERMS

ADAPTIVE CAPACITY, as it relates to infrastructure and built assets, describes the degree to which the physical elements of a system can absorb, withstand, or respond to climate change impacts without incurring damage.

CLIMATE is an expression of the composite weather conditions (e.g., temperature, precipitation, wind), including both statistical averages and the occurrence of extreme events, over a given period of time. The World Meteorological Organization recommends a 30-year period to adequately describe the climate of a given area.

CLIMATE CHANGE refers to a statistically significant variation in climate data or patterns over a given period of time, due to either natural climate variability or as a result of human activity.

CLIMATE CHANGE ADAPTATION describes measures taken in response to actual or projected climate change in order to eliminate, minimize, or manage related impacts on people, infrastructure, and the environment.

CLIMATE CHANGE MITIGATION refers to actions that reduce the production of greenhouse gases that cause climate change. Although some adaptation strategies have mitigation co-benefits, they are not specifically referenced in this guide.

CLIMATE CHANGE IMPACTS on infrastructure are, for the purposes of this guide, the resulting influence of climate change effects on the structural form or function of an asset (e.g., the buckling of train tracks due to extreme heat).

CLIMATE CHANGE VARIABILITY is the short-term fluctuation in weather conditions, usually over a period of a year or a few decades.

CLIMATE DRIVER is the manifestation of a change in climatic conditions through one or more weather variables, such as a change in precipitation or sea level rise, to create an impact.

EXPOSURE refers to the extent to which a system comes into contact with a hazard.

LARGE-SCALE INFRASTRUCTURE SYSTEMS serve large populations and tend to be focused on urban areas.

RISK is the combined function of the likelihood that a hazard will occur and the resulting consequences.

SENSITIVITY is the degree to which a built, natural or human system is directly or indirectly affected by or responsive to changes in climate conditions or related impacts.

SMALL-SCALE INFRASTRUCTURE SYSTEMS service smaller populations, ranging from villages to clusters or communities of households, and are often more relevant to rural areas.

VULNERABILITY is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. It is often defined as a combined function of exposure and sensitivity to the effects of climate change, minus the adaptive capacity of a system.
Extreme weather events such as droughts, heat waves, dust storms, forest fires, floods, and landslides, which already disrupt the lives of millions each year, are expected to increase in frequency and intensity with climate change. The impact of these sudden events, in addition to the gradual change in climate effects over time, will put added stress on vital water, sanitation, flood management, transportation, and energy infrastructure. Responding to the impacts of climate change presents a major challenge for developing countries lacking adequate resources, and it is therefore an important focus of the United States Agency for International Development’s (USAID) development assistance portfolio.

To help address this challenge, and consistent with Executive Order 13677 – Climate-Resilient International Development, USAID has developed the Global Climate Change, Adaptation, and Infrastructure Knowledge Management Support Project (a Task Order under the Architecture and Engineering Indefinite Quantity Contract or IQC) to articulate best practices in incorporating climate adaption in the planning and engineering design of USAID infrastructure activities.

Under this project, a suite of knowledge management products has been created, led by the Overarching Guide: A Methodology for Incorporating Climate Change Adaptation Infrastructure Planning and Design. The objective of the Overarching Guide is to support the consideration of climate change risks and adaptation in USAID infrastructure development activities. Serving as a technical companion volume to the 2014 USAID publication, Climate Resilient Development: A Framework for Understanding and Addressing Climate Change, the Overarching Guide provides engineering and non-engineering development professionals with a methodology to evaluate infrastructure vulnerability and select appropriate engineering design options to rebuild resilience.

As a part of the suite of tools for incorporating climate resiliency into engineering design, this particular guide concentrates on flood management infrastructure, with the overall objective of supporting the consideration of climate change risks and adaptation in USAID flood management infrastructure activities. This guide will be useful for those considering specific engineering design options to make flood management infrastructure more resilient in a climate altered future. It provides engineering and non-engineering development professionals with an overview of potential impacts on flood management activities and adaptation options, and guidance for utilizing a risk assessment methodology to determine appropriate design measures.

While the focus of this guide is on engineering design; broader elements such as service delivery and management of supply and demand are also proposed as they are closely associated with the optimum performance of potable water infrastructure. The focus of this document is not on mitigation of greenhouse gas emissions related to potable water infrastructure construction or operation.

A SUITE OF TOOLS

Accompanying this flood management guide are additional primers that focus on potable water structures, roadways, bridges, sanitation, and irrigation, that provide more detail on climate change impacts and appropriate adaptation responses and strategies for these other important infrastructure sectors.
THE IMPORTANCE OF CONSIDERING CLIMATE CHANGE IMPACTS IN FLOOD MANAGEMENT INFRASTRUCTURE

Climate change is likely to exacerbate issues and constraints concerning water resources and infrastructure. The risks associated with climate change are broad and diverse. They may include, for example, reduced availability of rainwater, surface water and groundwater resources, or physical damage to potable water storage, treatment and distribution systems from flooding. Changes in climate patterns and natural hazards are likely to affect the operational profiles of existing infrastructure and bring additional challenges to the development, construction, and operation of new infrastructure. It is important for practitioners and stakeholders to consider the nature and extent of climate change impacts on investments and activities related to both new and existing infrastructure.

When considering the impact of climate change on flood management infrastructure, it is important to understand the relevance and cost-effectiveness of climate change adaptation activities. If the infrastructure asset is a short-term or temporary solution, or if the project is small, it may not be necessary to fully assess longer term climate change risks to the investment. If the asset is large or expected to last more than three decades, climate change risks should be considered. For example, the design and construction of a dam with a design life of 100 years or more should consider climate change impacts. On the other hand, a small-scale pipeline that can be repaired cost effectively following an extreme climate event may not need to be fully climate resilient.

Climate stressors will also impact, and involve consequent risks to flood management infrastructure. The risks to these assets include physical damage or inadequate capacity to provide protection.

A STEPWISE APPROACH TO CLIMATE RESILIENT DESIGN

Following a climate resilience framework when developing and evaluating flood management infrastructure design will help practitioners improve the effectiveness of these investments. USAID’s Climate Resilient Development Framework promotes the adoption of development strategies and infrastructure activities that integrate risk considerations in order to create more climate resilient infrastructure and thereby enhance cost effectiveness of interventions. These goals can be realized by following a five-step approach to: 1) establish the context; 2) conduct a vulnerability assessment; 3) conduct a risk assessment; 4) develop an adaptation strategy; and 5) implement activities in support of climate resilient infrastructure (addressed in Chapter 3).

This framework should be used by practitioners to establish what climate change impacts existing or future infrastructure assets might be facing (e.g., sea level rise), flooding, drought, and more extreme heat days); whether or not the asset might be sensitive to those changes; and how such sensitivities impact the asset. The subsequent risk assessment will help identify those assets whose failure would have significant impacts on buildings, economic activities or public health. Adaptation strategies should then be defined and implemented.

ADAPTATION STRATEGIES AND RESPONSES

Responding to climate change impacts will require the selection of appropriate adaptation strategies. These strategies should be selected based upon the previous assessments conducted under the Climate Resilient Design Methodology (see Chapter 3) and take into consideration a country’s priorities, availability of resources, and temporal-scale of the activities.

The diverse array of adaptation strategies and responses for enabling more climate resilient infrastructure design can be categorized under four types of strategic approaches: 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. Each approach has advantages and disadvantages that are expanded upon in Chapter 3. Examples of climate impacts and risks, and adaptation measures relevant to potable water infrastructure are provided in Table 1.

A compendium illustrating adaptation strategies available to practitioners to address potential climate change related risks to flood management infrastructure is also provided in an Annex.

CASE STUDY

A climate change resilient infrastructure design case study is also provided to demonstrate the application of the methodology presented in this guide.

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<th>Climate Drivers</th>
<th>Climate Impacts and Risks</th>
<th>Adaptation Measures</th>
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| **Extreme Precipitation Events, Less Frequent but Higher Intensity Storms, Flooding** | • Higher precipitation would generate higher flows and increase erosion of structures and riverbanks, as well as riverbed instability reducing flood protection  
  • Larger floods can submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys  
  • Higher precipitation can increases upstream erosion and reservoir sedimentation, leading to reduced storage in reservoirs | • Consider future climate in design of asset to manage larger peak water flows  
  • Combine open space and stormwater storage to manage peak flows  
  • Provide training on the use of temporary flood barriers to protect critical infrastructure  
  • Provide flood education, awareness and emergency management training for at risk communities  
  • Revegetation of catchments to retain more precipitation |
| **Sea Level Rise, Storm Surge** | • Submersion or destruction of infrastructure, leading to increased flooding of coastal buildings and assets, potential loss of life  
  • Change in distribution of storm events may result in wider areas of impact in locations without sea wall protection | • Consider future climate in design of coastal protection assets  
  • Beach nourishment and dune construction  
  • Revegetation of coastal areas  
  • Storm surge barriers, barrier islands, and tide gates |
| **Drought, Wildfires** | • Heatwaves and low moisture levels could cause wildfires. Destruction of vegetative cover increases the potential for runoff during storm events, increasing the risk of flood | • Maintain and implement vegetation management practices that aim to minimize fire risk |
FLOOD MANAGEMENT INFRASTRUCTURE

Floods are overflows of water that submerge land areas that are typically dry. Floods originate from oceans and seas, or water bodies such as lakes or rivers damaging homes, businesses, infrastructure and causing human casualties. Floods can be local, impacting a neighborhood or community, or very large, affecting entire regions, plains, valleys, or deltas.

Most importantly, both types of floods, coastal and river, are natural events. They have been occurring for millions of years, continuously reshaping coastlines, estuaries, deltas, valleys, floodplains, and riverbeds. However, the magnitude of these events can be significantly increased by human activities such as urban development or deforestation, while their impacts and damages can be multiplied as development increases in floodplains and coastal areas.

FLOOD TRIGGERS

The main triggers for river floods are:

• Extreme rainfall events, or heavy precipitation, causing increases in river flows and elevations (i.e. levels). For example, Asian monsoon rains that can flood very large areas for days or weeks, or local thunderstorms affecting steep or urban areas causing flash floods in a matter of hours; and

• Snowmelt due to rapid temperature increase (often in Spring after heavy winter snowfalls).

Large floods can sometimes occur as a combination of both triggering events. River floods can also be caused by the failure of man-made dams (which can be earthen, rock-fill, concrete, or arch) or natural dams (such as ice-dammed lakes or debris dams formed after volcanic eruptions or landslides).

The main triggers for coastal or tidal flooding are:

• Atmospheric depressions (extreme examples include cyclones, typhoons and hurricanes) which cause sea levels to exceed normal elevations, while accompanying winds create tall and powerful waves. When depressions and high tides happen together, significant coastal areas can be submerged; and

• Earthquakes, volcanic eruptions and other natural events displacing large volumes of water cause tsunamis (i.e. tidal waves).

Finally, large flooding can also occur in estuaries and deltas due to a combination of river floods and high tides. This often happens during severe depressions that often are accompanied by heavy rainfalls (e.g. cyclones, typhoons and hurricanes).

Climate change is a significant threat to poverty reduction activities and could jeopardize decades of development efforts. From the very beginning, investment plans and the design process, development of new infrastructure and rehabilitation of existing infrastructure should be designed to be resilient to climate risks.
FLOOD IMPACTS
Floods result in both direct and indirect impacts:

**Direct impacts** include structural and property damage caused by the impact of flood waters, erosion, or submersion. Assets that may be damaged as a result of floods include buildings, transportation infrastructure, utilities, irrigation systems and farmlands. Vehicles, equipment and goods may also be damaged by floods. Floods may also result in the loss of life.

**Indirect damages** include:

- Loss of crops and livestock. This can be especially detrimental in developing countries where large populations rely on agricultural activities;
- Temporary decline in economic activities including tourism;
- Restricted access to food and other critical supplies including medicine;
- Disruption of transportation systems hindering recovery and relief efforts;
- Longer term economic impacts associated with the cost of recovery and losses associated from a disaster; and

- Exposure to diseases especially when water sources are polluted.

FLOOD MANAGEMENT
The following three main approaches are commonly implemented to avoid or mitigate flood damage:

1. **Flood risk assessment and mapping** to identify flood prone areas, along with specifics of the risk (probability, depths and speed of waters, duration of submersion); such studies can help to prevent flood damage by guiding land use and urban development, thus precluding the siting of critical infrastructure (hospitals, schools, water and power plants) in at-risk areas. It can also help to reduce damages by advising on the need to flood-proof existing buildings and adjusting the design of new ones;

2. **Forecasting and flood warning** systems, which monitor weather and help to reduce damages by alerting populations, before the flood, to evacuate or ready themselves, protect their belongings and flood-proof their residences and other infrastructures; and

3. **Flood management structures** can be used to protect urban and agricultural communities, homes, and other economically valuable areas, and the people residing in them, by:

- Delaying and abating floods (reservoir dams);
- Diverting flows of water (overflow or diversion weirs and channels, reservoirs and lakes, wetlands and other expansion areas);
- Preventing inundation (dikes, spurs, levees, and seawalls); or
- Preserving or increasing the flow capacity of riverbeds and canals (regular river bed maintenance, channel stabilization, and riverbank protection).

By keeping water out, flood management structures lessen harm to physical infrastructure and help to ensure the continuation of communities’ economic and social activities.

Flooding in the outskirts of Bangkok during the floods of 2011. Flooding caused widespread damage in many parts of the city.

Manila Water Sewage Treatment Plant constructed on top of the Metro Manila Development Authority (MMDA)’s flood management facility. The facility was constructed in this location as a response to scarce land in Manila. This plant was awarded recognition for project innovation.
**INTRODUCTION**

The overall objective of this guide is to support the consideration of climate change risks and adaptation in USAID flood management infrastructure development activities. It provides engineering and non-engineering development professionals with a guidance document demonstrating a step-by-step method for assessments and supporting technical information, including an overview of potential impacts on flood activities, adaptation options, case studies and resources. This guide will be useful for those considering how climate change may require specific infrastructure projects (e.g., a design for a specific dam or levee) to be altered to enhance resilience. This guide will also be useful to those considering how to meet service goals in a climate altered future.

This flood management guide accompanies an Overarching Guide that covers integration of climate change adaptation considerations into a broad range of USAID infrastructure activities. The overarching methodology offers a step-wise process for implementing a risk assessment framework. This guide is specific to flood infrastructure. Note that some content is repeated in both guides to maintain readability of each document.

**CLIMATE CHANGE IMPACTS ON FLOOD MANAGEMENT INFRASTRUCTURE**

Sea level rise will increase the risk of tidal inundation and coastal erosion. The risks associated with coastal storm surge will worsen as sea levels rise and the intensity of hurricanes, cyclones and typhoons increase. Climate change is also expected to increase the intensity of extreme rainfall events. More frequent and intense rain events will cause more river floods and notably more flash floods. In coastal environments, river floods may combine with coastal flood increasing the depth and extent of flood events. While tsunamis can cause significant coastal flooding, there is uncertainty about how climate change may impact the geological drivers of tsunamis.

The most important consequence of climate change is that since weather conditions may change, the climate assumptions upon which flood management structures (among others) were designed and built may no longer be appropriate and relevant. Existing structures may become inadequate, ineffective or even obsolete, if not dangerous (they may fail much more often than expected, and their failure may cause more damage than if they did not exist).

The design of new structures will also become problematic: if past weather patterns are no longer a yardstick to predict and size future events, what should designers rely on? Conversely, should existing structures be trusted to perform as designed and expected, to what extent, or should they be adapted?

There continues to be great need for national governments and development organizations to provide adequate flood protection for people and infrastructure in developing countries through investments and direct technical assistance. Decision making on appropriate planning, design, and operation and maintenance of flood management structures is affected by the local context, such as policies, development priorities, as well as local hydrology, topography, rainfall patterns, and existing infrastructure. But such decision making should also consider the nature and extent of future climate change and the resulting impacts on both new and existing flood management structures.

**HOW TO USE THIS GUIDE**

The overall objective of this guide is to support the consideration of climate change risks and adaptation in USAID flood management infrastructure development activities. It provides engineering and non-engineering development professionals with a guidance document demonstrating a step-by-step method for assessments and supporting technical information, including an overview of potential impacts on flood activities, adaptation options, case studies and resources. This guide will be useful for those considering how climate change may require specific infrastructure projects (e.g., a design for a specific dam or levee) to be altered to enhance resilience. This guide will also be useful to those considering how to meet service goals in a climate altered future.

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Flood engineering design relies heavily on statistical average and extreme weather conditions, so it is therefore essential to understand the implications of climate change to allow proper design of sustainable flood management structures. Sustainability needs to be considered in terms of both the physical condition and functional relevance, for example:

- A river embankment may be high enough but unexpectedly eroding due to increased flow velocities; or
- A sea wall may be structurally resilient but become ineffective as sea level rise leads to its frequent overtopping.

Appropriate decision making requires consideration of asset vulnerability, the cost of adapting to climate change, and the anticipated benefits.

The primary climate drivers referenced in this guide are identified below. Icons are provided for each climate driver and are used as visual aids throughout this guide. Additional natural hazards that are not explored in this guide but may affect infrastructure include tsunamis, earthquakes, volcanic eruptions, landslides and rockfalls.

The following sections provide an overview of the risks that climate change may pose to flood coastal and river management infrastructure and how to manage or minimize these risks in the development or rehabilitation of such structures. The range of risks discussed is not exhaustive; practitioners should conduct a detailed assessment at the project or program level to identify all relevant risks.

### CLIMATE DRIVERS

**EXTREME HEAT/HEATWAVES:** Extreme temperatures are location specific. Heatwaves are prolonged periods of excessively hot weather. Likely increase in extreme air temperature and heatwaves in most areas.

**DRYING TRENDS/DROUGHT:** A prolonged dry period in a natural climate cycle which results in a shortage of water. Likely increase in drought conditions in some areas through a warming of air temperature and decrease in precipitation.

**EXTREME PRECIPITATION/FLOODING:** Extreme precipitation events are location specific and can cause flooding when downpours exceed the capacity of river or urban drainage systems. Uncertain climate projections, expected to intensify in some areas.

**STORM SURGE:** The difference between the actual water level under the influence of a meteorological disturbance (storm tide) and the level which would have been attained in the absence of the meteorological disturbance (i.e. astronomical tide). Sea level rise exacerbate storm surge height.

**SEA LEVEL RISE:** Anticipated sea level changes due to the greenhouse effect and associated global warming. Leads to changes in erosion and accretion, long term inundation, exacerbate storm surge and tsunami height.

**DAMAGING STORMS (WIND, LIGHTNING):** Severe weather systems involving damaging winds and heavy rainfall downpour, including tornados, hailstorms, tropical cyclones and hurricanes. Uncertain climate projections.

**WILDFIRE:** A massive and devastating fire which destroys forests, grasslands, and crops, kills livestock and wild animals, damages or destroys settlements and puts lives of inhabitants at risk. Uncertain climate projections.
KEY CONSIDERATIONS IN IDENTIFYING IMPACTS TO FLOOD MANAGEMENT INFRASTRUCTURE  
Climate change is likely to impact flood management infrastructure assets through modification in the pattern of extreme climatic events, which includes storms and storm surge, floods, and drought; or through gradual changes in seasonal or annual patterns of temperature, solar radiation, precipitation, and sea level rise. Evaluating the impact of climate change and risk to flood management infrastructure, requires addressing two overarching concerns – the timeframe for the asset’s productive lifespan and required capital costs. While engineering design always considers some measure of extreme weather conditions when designing or rehabilitating infrastructure, it is important to consider a temporal scale that is appropriate to the anticipated life of the asset as well as the cost-effectiveness of climate resilience options.

Temporal scale of the planned infrastructure asset will affect the degree to which risk is addressed. For example, if an infrastructure asset is designed as a short-term or temporary solution or if it is a relatively small project, it may be unnecessary to fully assess long-term climate related risks. If it is a large-scale project or an asset that is expected to function for the long-term, a longer timeframe would need to be considered.

KEY CONSIDERATIONS  
In developing countries, climate adaptation measures will be required to reduce the costs and disruption caused by climate change. Keeping in mind the key aspects noted above, it will also be important when designing or rehabilitating infrastructure systems to follow certain principles that will help create greater resiliency by planning not just for the current climate, but for the climate scenario projected for the entire design life of the infrastructure asset.

Impacts are a function of changes in frequency and magnitude of flood events and temperature fluctuations. Changes in precipitation and storm intensity affect the magnitude and frequency of flood events and, thus, impact the need for flood management, or the scale of damage to existing flood infrastructure and assets that support human life. Sea level rise would also impact the effectiveness of existing flood structures. Increase in mean temperatures can also alter the profile or timing of flood events associated with snow melt or glacial environments (e.g. glacial lake outbursts).

Impacts are a function of a flood structure’s location, design life, function, operation, and condition. Many characteristics of the structure and its location influence the likelihood and extent of climate change impacts. These must be considered in establishing the context for the climate change risk and vulnerability assessment. Questions about the condition of existing infrastructure (Has it been maintained? How is it being operated? What is its current protection level?) are important to evaluate as part of a comprehensive assessment.

Climate change can cause direct physical impacts to assets and indirect impacts including loss of service. Changes in the pattern of extreme events can directly impact the physical integrity of built structures in a variety of ways, causing loss of service. Gradual changes can also exert impacts, such as in the degradation of materials due to increased exposure to erosion or salinity from sea level rise.

Indirect impacts and cascading consequences can be more difficult to identify than direct impacts, but they should nevertheless be considered. For example, power failure or restriction of road access during an extreme weather event may prevent the safe operation of flood control infrastructure (i.e. flood gates). Higher velocity river flows may cause erosion of riverbanks and channel instability, thus leading to existing flood infrastructure being bypassed by flood waters.

Current infrastructure design is based on historical data and experience. Most existing infrastructure assets were designed based on historical climate data, such as average rainfall and runoff in an area, or historic flood events. However, the pace of climate change means that historic data may no longer be relevant for longer-term infrastructure performance. Climate change may cause shorter asset life spans or require early rehabilitation as infrastructure degradation accelerates.

Climate variability or increased frequency of extreme events may mean that infrastructure is no longer optimally designed for even short-term purposes. To illustrate, it is likely to be preferable to design culverts and drainage systems associated with roadways to a higher standard than current design guidance in anticipation of future extreme flood events. These situations can be exacerbated in less developed countries where design standards and climate project data may be out of date or nonexistent.
POTENTIAL IMPACTS ON COASTAL FLOOD MANAGEMENT INFRASTRUCTURE

The climate change effects that will impact flood management infrastructure in coastal areas include sea level rise, increased storm intensity, and increased storm frequency (see Table 2). Higher sea levels will occur due to climate change, and this will increase flood inundation in coastal areas. The magnitude of severe winds over water, such as those during hurricanes, cyclones and typhoons, is expected to increase the severity and intensity of storm surges that impact coastal areas. Furthermore, increased storm frequency is expected to increase flood damages and coastal erosion. All of these potential impacts are likely to result in higher costs for maintaining existing flood infrastructure, and for building new infrastructure, particularly since the new infrastructure will need to be larger and more robust.

CLIMATE CHANGE EFFECTS ON COASTAL FLOODING

Sea level rise will increase inundation of low-lying coastal areas. Flooding may extend to larger geographic areas with higher river flows. Higher sea levels will further worsen flooding when combined with high tides, storm surge, and river flooding. Increased flooding could increase the number of homes and assets affected by coastal flooding events. Sea level rise can also contribute to higher groundwater, which may affect the stability and integrity of coastal buildings and structures.

Increased storm intensity will result in greater coastal flood magnitude. The increase in rainfall intensity is likely to increase the flood hazard to people and assets including homes, buildings, road and communication networks and other infrastructure in coastal areas. Flood prone areas will experience higher damage potential to built structures, and greater potential for loss of life, while new areas will become flood liable.

Increased storm frequency will impact the frequency of flood damages and hasten coastal erosion. This in turn will reduce the stability, and lifespan, of coastal flood protection infrastructure.

NATURAL PROTECTION

Natural materials and systems can be used to provide protection against coastal flooding. These can include physical structures such as gravel bars and sand dunes as well as ecosystems such as salt marshes and mangrove forests. Gravel bars and sand dunes function much like typical man-built flood protection structures (e.g. sea walls). Mangroves and wetlands provide protection against storm driven waves, tsunamis minimizing shoreline erosion by buffering wave energy. Mangroves and wetlands also have the capacity to regenerate after damage from storms. Restoring or enhancing these natural features can be considered adaptation measures.

IMPACTS ON COASTAL FLOOD MANAGEMENT STRUCTURES

Sea level rise will decrease the protection level provided by flood structures. This can happen by decreasing their free-board (altitude difference between sea level and top or crest of the structure). It will increase the probability and thus frequency of these being over-topped by waves, tides, storms, or tsunamis. Sea level rise may also degrade or erode the foundations of such structures and shorten their lifespan, either directly or through rising groundwater tables.

Such impacts deserve serious considerations since the coastal zone (area both within 100 km of the coast and 100 m altitude) is home to 50% of the global population, and includes 65% percent of the world’s largest cities (those with over five million people).
Increased storm intensity will result in greater coastal flood magnitude. This will also increase the likelihood that flood protection structures would be insufficient or over-topped. These structures will have to be raised, enlarged or extended, or new larger structures will have to be designed and built, thus requiring additional capital expenses.

Increased storm frequency will impact the frequency of damage to structures and hasten their erosion. This can result in the reduction of their lifespan, and possibly cause premature failure, either through cumulative damage or during a storm. The flood structures will have to be regularly inspected and reassessed, and possibly repaired, reinforced, or rehabilitated to continue performing properly. Structures such as floodgates will have to be operated more frequently or differently than initially planned, leading to higher wear and tear.

Increased amount of precipitation will increase erosion rates in upstream watersheds and sedimentation in lower rivers and floodplains. This, combined with increased average surface flows in streams and rivers, will lead to increased riverbank instability, faster riverbed alteration. This in turn will impact flood conveyance, may increase the frequency of flooding, and will also influence the lifespan of river flood structures.

Land availability may be an issue for the construction, extension or upgrade of flood protection structures.

**POTENTIAL IMPACTS ON RIVER FLOOD MANAGEMENT INFRASTRUCTURE**

The potential climate change impacts that may affect flood management infrastructure along rivers include increased precipitation and temperatures (see Table 2). These are likely to increase the magnitude and frequency of flood events, result in higher maintenance costs for existing flood management infrastructure, and costs for building new infrastructure.

**CLIMATE CHANGE EFFECTS ON RIVER FLOODING**

Increased precipitation intensity will increase the magnitude of flood events in streams, rivers, and urban channels or stormwater networks, with deeper, faster, and wider flooding. This increase in intensity is likely to increase the flood hazard to people and assets, such as homes, other buildings, road and communication networks and other infrastructure in river valleys, floodplains, deltas and estuaries. Flood prone areas will experience higher potential damage to built structures and greater potential for loss of life, while new areas will become vulnerable to flooding.

Increased storm frequency will impact the frequency of damage to structures and hasten their erosion. This can result in the reduction of their lifespan, and possibly cause premature failure, either through cumulative damage or during a storm. The flood structures will have to be regularly inspected and reassessed, and possibly repaired, reinforced, or rehabilitated to continue performing properly. Structures such as floodgates will have to be operated more frequently or differently than initially planned, leading to higher wear and tear.

**Increased storm intensity will result in greater coastal flood magnitude.**
# TABLE 2: FLOOD MANAGEMENT INFRASTRUCTURE

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<th>Climate Drivers</th>
<th>Impacts and Consequent Risks</th>
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<td><strong>Coastal Structures (embankments, seawalls, spurs, etc.)</strong></td>
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| ![Image](image1) Increased coastal inundation and frequency or intensity of flooding from storm events; sea level rise | • Submersion or destruction of infrastructure, leading to increased flooding of coastal buildings and assets, potential loss of life  
• Change in distribution of storm events may affect may result in wider areas of impact or impact on areas without sea wall protection  |
| **River Structures (embankments, levees, dikes, diversion channels, etc.)** | |  
| ![Image](image2) Increased frequency of extreme precipitation events and flooding | • Higher precipitation would generate higher flows and increase erosion of structures and riverbanks, as well as riverbed instability, thereby lowering flood protection  
• More intense precipitation events generate larger floods which can submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys  |
| **River Dams (large and medium, hill-lakes)** | |  
| ![Image](image3) Increased frequency of extreme precipitation events and flooding | • Higher precipitation would increases upstream erosion and reservoir sedimentation, leading to reduced storage and flood protection  
• More intense precipitation events generate larger floods which can exceed storage capacity, or submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys  |
| ![Image](image4) Change in temperature and precipitation patterns | • Failure of ice-dammed lakes generates large floods which can submerge or destroy downstream structures, leading to increased damages and potential loss of life in floodplains and river valleys  |
| ![Image](image5) Drought, Wildfires | • Heat waves and low moisture levels could cause wildfires. Destruction of vegetative cover increases the potential for runoff generation during storm events, increasing the flood potential  |
| **Urban Stormwater Networks** | |  
| ![Image](image6) Increased frequency of extreme precipitation events and flooding | • More intense precipitation events generate larger floods which may overflow structures, leading to increased damages and potential loss of life, notably in dense urban areas  |
**IMPACTS ON RIVERINE FLOOD MANAGEMENT STRUCTURES**

Increased precipitation intensity will result in greater river flood magnitude. Thereby also increasing the likelihood that flood protection structures would be insufficient, overflowed (networks) or over-topped (embankments, levees). These structures will have to be raised, enlarged or extended, or new larger structures will have to be designed and built, thus requiring additional capital expenses.

Increased precipitation frequency will impact the frequency of damage to structures and hasten their erosion. This can result in the reduction of their lifespan, and possibly cause premature failure, either through cumulative damage or during a flood. The flood structures will have to be regularly inspected and reassessed, and possibly repaired, reinforced, or rehabilitated to continue performing properly. Structures such as controlled dam spillways will have to be operated more frequently or differently than initially planned, leading to higher wear and tear.

Land availability may be an issue or concern for the construction, extension or upgrade of flood protections structures.

**RIVER GEOMORPHOLOGY**

A river is a natural stream of water that erodes, carries and deposits sediments along its reach. As it does so, its riverbed evolves, getting deeper or shallower, wider or narrower, straighter or more winding. All these changes are usually gradual but can be quite drastic during large flows (riverbanks can collapse or get significantly eroded, while meanders can appear, get much more pronounced, or even be cut-off; bars and islands can appear). Flood conveyance and thus flooding along riverbanks can be impacted by changes in a river’s size and shape.

The size (width and depth) and shape (meanders, bars and islands, braiding) of a river is a constantly evolving equilibrium that is a function of:

- The precipitation regime, which impacts upper watershed erosion and when combined with the topography, the soil type and the vegetation determines the flow rates of the river;
- The type of soils and the geology in the river valley, combined with vegetation, impact how fast erosion can occur along riverbanks; and
- The overall valley slope, which impacts where and how fast erosion and sedimentation occur along the reach of a river.
CHAPTER 3
A CLIMATE RESILIENT INFRASTRUCTURE METHODOLOGY

ENABLING CLIMATE RESILIENT PLANNING AND DESIGN OF FLOOD MANAGEMENT INFRASTRUCTURE

This chapter provides a step-wise methodology to enable practitioners to include climate change considerations in the design of new structures or the evaluation of existing ones (see Figure 2).

• **STEP 1** establishes the context of the assessment defining the asset and the climate impacts that will be the focus of the assessment.

• **STEP 2** considers the vulnerability (exposure, sensitivity, and adaptive capacity) of the assets screening those that require more detailed analysis.

• **STEP 3** identifies, analyzes and evaluates the subsequent risks (combining likelihood with consequences).

• **STEP 4** develops adaptation strategies to address the most significant risks.

• **STEP 5** guides the implementation, monitoring and evaluation of adaptation solutions.

In applying the methodology, the majority of the effort is focused on Steps 3 and 4. Risk assessment and adaptation to climate change impacts should be part of a multi-criteria decision-making process (along with other technical, socio-cultural, environmental, economic, and financial factors) that reviews solutions and options during engineering planning and design. While the capital costs of creating infrastructure assets that are more resilient to climate change impacts may guide the adaptation strategy selection and design, a proactive approach when possible and affordable is often more cost-effective than being reactive. It will ultimately be more economical to build stronger and better located assets than to rebuild or repair structures following a disastrous event, in addition to other costs such as healthcare and clean-up that may result from failure of an asset.

If a risk management process is already in place for infrastructure activities, the following framework can be used to assess the adequacy or identify gaps in the process. If there is no existing risk management process in place, this step-wise approach can be used to establish such a process.

ALTERATIONS IN FLOOD ENGINEERING DESIGN

Examples of alterations in flood engineering design to account for climate change:

• Existing dam: enlargement of existing spillway to accommodate potentially more intense precipitation events and thus possible larger floods in the near future; and

• Coastal protection: proposed sea wall is built further inland to provide more durable flood protection; due to projected sea level rise, the initial location would have been highly sensitive to erosion.

STEPWISE APPROACH FOR CLIMATE RESILIENT INFRASTRUCTURE PLANNING AND DESIGN

The management of climate change risks in USAID infrastructure activities can be facilitated by the following five-step process including:

5 STEP PROCESS

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Establishing the Context</td>
</tr>
<tr>
<td>2</td>
<td>Vulnerability Assessment</td>
</tr>
<tr>
<td>3</td>
<td>Risk Assessment</td>
</tr>
<tr>
<td>4</td>
<td>Development of Adaptation Strategies</td>
</tr>
<tr>
<td>5</td>
<td>Implementation</td>
</tr>
</tbody>
</table>

Collectively, these steps establish a climate resilient design methodology to be used when determining appropriate engineering design actions for more climate resilient structures.

This process will help establish whether or not an existing or future infrastructure asset is vulnerable and at risk from climate change impacts. Tools, in the form of checklists, worksheets, or matrices, can support practitioners in undertaking these steps and are provided in this chapter.
FIGURE 2: USAID’S CLIMATE-RESILIENT DEVELOPMENT FRAMEWORK

**COMMUNICATION AND CONSULTATION WITH TECHNICAL EXPERTS, IMPLEMENTING PARTNERS AND STAKEHOLDERS**

<table>
<thead>
<tr>
<th>DEFINE ASSET (e.g., reservoir, transmission line, roadway, water treatment plant)</th>
</tr>
</thead>
</table>

**IDENTIFY CLIMATE IMPACTS**
What are the expected changes in natural hazard and climate change patterns for the region?

**EXPOSURE ANALYSIS**
Is the asset exposed to the anticipated climate change impacts?

**SENSITIVITY ANALYSIS**
To what degree is the asset affected, either adversely or beneficially, by the climate change impacts?

**LIKELIHOOD ANALYSIS**
What is the probability of and confidence in the occurrence of the anticipated climate change impact?

**CONSEQUENCE ANALYSIS**
What are the economic, social, or ecological outcomes associated with the climate impact on the asset?

**RISK ANALYSIS**
Combine likelihood and consequence to rank the risk.

**RISK EVALUATION**
Is the risk acceptable?

**DEVELOPMENT & COMPARISON OF ADAPTATION RESPONSES**
How should engineering design be adjusted to account for climate change impacts? What are the optimal (multi-criteria) responses?

**PROJECT APPRAISAL**
Further refine options (e.g., cost benefit)

**RESOURCE-BASED ANALYSIS**
Availability of and access to resources

**BEST PRACTICES**
Incorporate lessons learned in future design and planning process

**MONITORING & EVALUATION**
Monitor and evaluate for change in risk status

**STEP 3** Vulnerability Assessment

- The Asset is Vulnerable to Climate Change Impacts
  - Highly or Moderately Sensitive
  - Low Sensitivity or Not Sensitive

**STEP 4** Adaptation Strategy

- The Risk Requires Development of an Adaptation Strategy
  - Extreme, High, or Medium Risk
  - Not Significant, or Low Risk

**STEP 5** Implementation

Assessment complete, no further action needed
The first step in the overall approach is to define the service to be delivered by the infrastructure activity in the face of future climate change. Establishing the context notably includes assessing the probability of flooding occurring, and defining the protection levels to be provided by flood management infrastructure within the context of future climate change.

**DEFINING INFRASTRUCTURE OBJECTIVES**
Natural risks, such as floods, are often defined and characterized based on their probability of occurrence, with the understanding that the magnitude and severity of a rarer event will be greater than that of a more common event.

Flood management structures are designed for protection up to a certain level of probability defined by the return period of the design event, usually the 10-yr, 20-yr, 50-yr or 100-yr flood (or even larger flood events in the case of dam spillways and levees).

When the n-yr flood (n being the return period) is chosen as a design event, this means that resulting structures should be able to provide flood protection up to that critical level, often allowing for an additional safety margin. Greater events would require higher, more expensive protection, but are also rarer (less probable). It is not possible to protect against every possible flood event, as such, flood management infrastructure typically manages floods up to a certain level, but cannot control or eliminate complete all flood risk.

If poorly designed, constructed, operated or maintained, flood protection structures may increase the risks by providing a false sense of security and encouraging settlements or economic activities in hazard-prone areas. Hurricane Katrina in New Orleans provides an example of development occurring in a protected area that was devastated when flood protection infrastructure failed as the result of an extreme weather event.

Consideration should also be given to the broader system that the assets are integrated with. Once the scope of the assets are defined, information about the assets is needed to inform the later stages of the assessment. Typically an inventory or database is developed that contains information on each asset’s criticality, function, condition, location, design and interdependences. For flood management infrastructure, it is important to review the presence of people, businesses, and other resources that are located in areas with the greatest likelihood of being affected by flood events. This would be based on physical location within a floodplain or other areas of historic flooding, in areas of poor drainage that might be subject to flash flooding, or in coastal areas.

From a system perspective, it is important to consider the beneficial role a flood event may have on a region. For example, annual floods bring vital nutrients in delta regions that grow rice, thus sustaining local communities. Increased magnitude of flood events in these communities can cause devastating damage, but interventions that stop flooding altogether can have significant negative socio-economic impacts.

**RETURN PERIOD**
The Annual Exceedance Probability (AEP) or annual probability of occurrence of an event matching or exceeding the n-year event (n being the period of return) is 1/n. So a 10-yr (resp. 100-yr) flood is not a flood that comes every 10 (resp. 100) years but a flood whose probability of occurrence is 1/10 = 10 percent (resp. 1/100 = 1 percent) on any given year.
UNDERSTANDING AND IDENTIFYING CLIMATE AND NON-CLIMATE STRESSORS

Gathering data and information via research will also help practitioners understand current hazards, how they may be affected by climate change, and identify relevant internal and external factors that are within or outside the control of the project team or organization.

Internal factors include objectives and criteria governing investment decisions, engineering specifications, or service delivery targets. External factors include socio-economic (financial resources, economic activities, culture and traditions, education, and socio-demographic conditions); biophysical aspects (biodiversity, geomorphology, hydrology, and soils); and institutional arrangements (governance, regulations, and stakeholder relationships among public, private, and voluntary sectors).

Most of these factors will be reviewed as part of typical planning infrastructure development activities. The additional element that must be integrated involves climate science modeling for the region to understand what the likely changes in climate variables such as rainfall patterns, extreme temperature, or storm events might be. For coastal projects, projected sea level rise and storm surge must also be reviewed.

SOURCING CLIMATE DATA

USAID development projects are undertaken in a variety of geographic settings and country contexts involving floodplains, coastal atolls, mountainous and arid regions. When evaluating climate impacts and risks to infrastructure assets, understanding the context by collecting climate data and projected trends for specific geographic locations will be a critical first step. In many developing country settings, detailed climate observations and projections may be scattered, inaccurate, incomplete, or not available. Lack of weather stations, difficulties in terrain, and inaccuracies from data collection (i.e., human error) are all factors that can create uncertainty. Practitioners can respond by making conservative estimates based on available data and source data at the regional and continental scales.

In some situations, lack of specific climate data may be overcome by consulting available data in similar parts of the region, traditional knowledge and mapping, drawing from studies conducted under similar conditions or by conducting new studies. The USAID Overarching Guide: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design contains additional information and guidance on climate data and trends as well as information sources that may assist with this step.
CONDUCTING A VULNERABILITY ASSESSMENT

1. Analyze exposure of the asset to hazards using spatial information
2. Analyze sensitivity of the asset using a sensitivity matrix
3. Consider adaptive capacity

The second step in the overall approach considers the degree to which an infrastructure asset is susceptible when exposed to hazards identifying those that warrant more detailed investigation in Step 3. The vulnerability screening involves understanding an asset’s vulnerability to specific climate change impacts over time. Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change defines vulnerability as a function of an asset’s exposure, sensitivity and adaptive capacity to a specific climate hazard.

DETERMINING ASSET EXPOSURE
Exposure is the nature and degree to which a structure or asset is subject to a climate impact. For example, a stormwater network exceeded by a 5 year extreme rainfall event would be highly exposed to this climate stressor, whereas a dike that would only be overtopped during a 100-year storm surge event would have medium exposure.

For each planned activity, determine whether or not it is likely to be exposed to the impacts identified in Step 1. Spatial information related to hazards will assist this process (e.g. flood hazard or other planning maps). Only those assets deemed to be exposed to particular climate change impacts identified in Step 1 should progress to the assessment of sensitivity. If an asset or project site is not exposed to climate change impacts, then the assessment is complete at this point.

DETERMINING ASSET SENSITIVITY
Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate stressors. For example, a substation providing power to flood infrastructure may

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be more sensitive to flooding than the dam wall itself as a dam wall is designed to function when in contact with water, while electrical equipment is not. Table 3 outlines the levels of sensitivity ranging from Not Sensitive to High Sensitivity. Using this scale, project elements that are rated as having a Moderate or High Sensitivity would be deemed vulnerable to the climate impacts associated with the relevant climate hazard and be the focus of the risk assessment. To help inform sensitivity assessments, Table 4 provides a summary of the likely sensitivity of different types of infrastructure to different climate hazards.

**TABLE 3: LEVELS OF SENSITIVITY TO CLIMATE CHANGE IMPACTS**

<table>
<thead>
<tr>
<th>Level of Sensitivity</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOT Sensitive</td>
<td>• No infrastructure service disruption or damage</td>
</tr>
</tbody>
</table>
| LOW Sensitivity      | • Localized infrastructure service disruption; no permanent damage  
                      | • Some minor restoration work required |
| MODERATE Sensitivity | • Widespread infrastructure damage and service disruption requiring moderate repairs  
                      | • Partial damage to local infrastructure |
| HIGH Sensitivity     | • Permanent or extensive damage requiring extensive repair |

Moderate or high sensitivity impacts are considered vulnerable and should be the focus of the risk assessment.

**TABLE 4: FLOOD MANAGEMENT INFRASTRUCTURE**

<table>
<thead>
<tr>
<th>Climate Drivers</th>
<th>Impacts and Consequent Risks</th>
</tr>
</thead>
</table>
| Coastal Flood Containment Structures (Embankments, Seawalls, Spurs) | • Submersion or destruction of infrastructure, leading to increased flooding of coastal buildings and assets, potential loss of life  
  • Change in distribution of storm events may affect may result in wider areas of impact or impact on areas without sea wall protection |
| River Flood Containment Structures (Embankments, Levees, Dikes, Diversion Channels) | • Higher precipitation can generate higher flows and increase erosion of structures and riverbanks, as well as riverbed instability, thereby lowering flood protection  
  • More intense precipitation events generate larger floods which can submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys |
| River Dams (Large and Medium, and Ice Dams) | • Higher precipitation can increase upstream erosion and reservoir sedimentation, leading to reduced storage and flood protection  
  • More intense precipitation events generate larger floods which can exceed storage capacity, or submerge or destroy structures, leading to increased damages, and potential loss of life in floodplains and river valleys |
| Change in temperature and precipitation patterns | • Failure of ice-dammed lakes generates large floods which can submerge or destroy downstream structures, leading to increased damages, and potential loss of life |
| Urban Stormwater Networks | • More intense precipitation events generate larger floods which may overflow structures, leading to increased damages and potential loss of life, notably in dense urban areas |
ASSESSING ADAPTIVE CAPACITY

Following the determination of an asset as vulnerable, practitioners may also need to consider the adaptive capacity for the infrastructure system. This step is not critical to the vulnerability screening process; however, it may provide useful information to inform the consequence discussion in Step 3.

Adaptive capacity is generally considered as a social component when working with soft infrastructure. When working with built or hard infrastructure, adaptive capacity refers to the ability to anticipate, prepare, and recover from climate impacts.

From a system perspective, this may be assessed by looking at core economic drivers in-country (or in similar contexts if not readily available), such as access to health services and education, resource strength in terms of wealth and human, strength of networks, institutions leadership, and disaster response mechanisms. Focusing on specific infrastructure, consideration may be given to the potential for supplementary capacity (e.g. redundancy), likely duration of a disruption to service or the duration of repairs to return an asset to operation (e.g. rebuilding a seawall).
The third step of the approach enables practitioners to consider risks once the vulnerability of an asset or project has been established. A risk assessment provides an analytical framework with qualitative descriptors for likelihood and consequences in a resulting risk matrix. Only those assets that have been identified as vulnerable in Step 2 need to be analyzed for risk.

Risks are often expressed as the combination of the consequences of an event and the associated likelihood of it occurring:

\[
\text{RISK} = \text{CONSEQUENCES} \times \text{LIKELIHOOD}
\]

This approach is aligned with traditional risk management principles (e.g. ISO 31000:2009 Risk management—Principles and guidelines). Exposure and sensitivity data gathered in Step 2 can be used to inform the rating of likelihood and consequences.

**CONDUCTING A RISK ASSESSMENT**

1. Define the likelihood of climate impacts occurring
2. Understand the consequences of climate impacts
3. Conduct a risk analysis and develop a risk rating matrix
4. Accept the appropriate level of risk and adaptation needs
LIKELIHOOD OF CLIMATE IMPACTS
Table 5 provides examples of qualitative definitions that can be used to characterize the likelihood of a risk occurring. The probability of a risk occurring is often described in qualitative terms. Only when there is sufficient data and capability can a quantitative description of likelihood be made, where the time horizon is the life of the asset.

The level of certainty in determining the likelihood of a climate impact largely depends on the scale and certainty that the climate modeling exercise will yield (e.g., more frequent heat waves), changes in hydrological patterns (e.g., recurring floods), variations in coastal environments (e.g., sea level rise), and climate-driven gravitational hazards (e.g., higher frequency of rock falls, mudslides and avalanches). Regional models will likely yield more precise results with a smaller range of projections, providing greater certainty. Assumptions regarding uncertainties associated with the model, or a hypothesis when modeling is not possible, should be clearly articulated.

<table>
<thead>
<tr>
<th>Level of Likelihood</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Almost Certain</td>
</tr>
<tr>
<td>4</td>
<td>Likely</td>
</tr>
<tr>
<td>3</td>
<td>Possible</td>
</tr>
<tr>
<td>2</td>
<td>Unlikely</td>
</tr>
<tr>
<td>1</td>
<td>Rare</td>
</tr>
</tbody>
</table>

CONSEQUENCES OF CLIMATE IMPACTS
It is important to understand the consequences associated with an asset being impacted by a climate hazard. In some instances, the consequences can be very specific and defined for each sub-component of a large infrastructure system. Defining consequences is ideally done in a workshop setting with key stakeholders to identify important criteria to be used to assess consequences. There may be one or several criteria used, depending on the project. Examples of consequence criteria which could be considered are listed below. Table 6 provides example definitions for rating each consequence criteria.

- **Asset Damage.** Damage requiring minor restoration or repair may be considered minor while permanent damage or complete loss of an asset would be considered to be a significantly higher consequence.

- **Financial Loss.** A high repair or capital replacement cost would be of major consequence compared to a cheaper repair or replacement cost.

- **Loss of Service.** As an example, a water system serving a large-scale industry with high water use requirements would be of major regional consequence compared to one serving a small-scale industry using less water.

- **Health and Safety.** A system serving a large number of people would be of major consequence compared to a system serving a smaller number. Casualties or other acute public health consequences would weigh more heavily.

- **Environmental Considerations.** Damage to a wastewater system adjacent to a local drinking water source, for example, would be of major polluting consequence compared to a system isolated from a local water source.

- **Reputation.** Loss of service, health or environmental impacts may affect the reputation of the responsible agency.
<table>
<thead>
<tr>
<th>Level of Likelihood</th>
<th>Definition</th>
</tr>
</thead>
</table>
| **5** Catastrophic   | • **Asset Damage:** Permanent damage and / or loss of infrastructure.  
                        • **Loss of Service:** Widespread and extended (several weeks) interruption of service of the agreed Level of Service; result in extreme contractual penalties or contract breach.  
                        • **Financial Loss:** Asset damage > annual maintenance budget or 75% of CAPEX value.  
                        • **Health / Safety:** Substantial changes to the health and safety profile; risk of multiple fatalities as a result of extreme events.  
                        • **Reputation:** Irreversible damages to reputation at the national and even international level / Public outrage. |
| **4** Major          | • **Asset Damage:** Extensive infrastructure damage requiring extensive repair / Permanent loss of local infrastructure services.  
                        • **Loss of Service:** Widespread and extended (several days) interruption of service for less than 50% of the agreed Level of Service; result in severe contractual penalties.  
                        • **Financial Loss:** Asset damage 50%+ of annual maintenance budget or 25% of CAPEX value.  
                        • **Health / Safety:** Marked changes in the health and safety profile, risk of severe injuries and even fatality as a result of extreme events.  
                        • **Reputation:** Damage to reputation at national level; adverse national media coverage; Government agency questions or enquiry; significant decrease in community support. |
| **3** Moderate        | • **Asset Damage:** Damage recoverable by maintenance and minor repair / Partial loss of local infrastructure.  
                        • **Loss of Service:** Widespread interruption of service for less than 20% of the agreed Level of Service; result in minor contractual penalties.  
                        • **Financial Loss:** Asset damage > 10% but < 25% of annual maintenance budget or 5% of CAPEX value.  
                        • **Health / Safety:** Noticeable changes to the health and safety profile, risk of severe injuries as a result of extreme events.  
                        • **Reputation:** Adverse news in media / Significant community reaction. |
| **2** Minor           | • **Asset Damage:** No permanent damage / Some minor restoration work required.  
                        • **Loss of Service:** Localized interruption of service for less than 10% of the agreed Level of Service.  
                        • **Financial Loss:** Asset damage > 5% but < 10% of annual maintenance budget or 1% of CAPEX value.  
                        • **Health / Safety:** Slight changes to the health and safety profile; risk of minor injuries as a result of extreme events.  
                        • **Reputation:** Some adverse news in the local media / Some adverse reactions in the community. |
| **1** Insignificant   | • **Asset Damage:** No infrastructure damage.  
                        • **Loss of Service:** Localized interruption of service for less than 1% of the agreed Level of Service (LoS).  
                        • **Financial Loss:** Asset damage < 5% of annual maintenance budget or negligible CAPEX value.  
                        • **Health / Safety:** Negligible or no changes to the health and safety profile or fatalities as a result of extreme events.  
                        • **Reputation:** Some public awareness. |
CONDUCTING A RISK ANALYSIS

Once the likelihood and consequence are defined, the risk level is determined by multiplying the likelihood value by the consequences value to result in a score from 1 (Low) to 25 (Extreme). Generally, the resulting score will be assigned one of five levels of risk: Not Significant, Low, Medium, High, or Extreme (Table 7).

TABLE 7: RISK RATING MATRIX

<table>
<thead>
<tr>
<th>Level of Risk</th>
<th>Consequence Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td>Likely (4)</td>
<td>Low (4)</td>
</tr>
<tr>
<td>Possible (3)</td>
<td>Low (3)</td>
</tr>
<tr>
<td>Unlikely (2)</td>
<td>Low (2)</td>
</tr>
<tr>
<td>Rare (1)</td>
<td>Not Significant (1)</td>
</tr>
</tbody>
</table>

TABLE 8: EXAMPLE RESPONSES AND ACCEPTABILITY FOR DIFFERENT LEVELS OF RISK

<table>
<thead>
<tr>
<th>Level of Risk</th>
<th>Definition</th>
</tr>
</thead>
</table>
| EXTREME ≥ 20 | • Extreme risks demand urgent attention at the most senior level and cannot be simply accepted as a part of routine operations  
• These risks are not acceptable without treatment |
| HIGH 12-16 | • High risks are the most severe that can be accepted as a part of routine operations without executive sanction, but they are the responsibility of the most senior operational management and reported upon at the executive level  
• These risks are not acceptable without treatment |
| MEDIUM 5-10 | • Medium risks can be expected to form part of routine operations, but they will be explicitly assigned to relevant managers for action, maintained under review and reported upon at the senior management level  
• These risks are possibly acceptable without treatment |
| LOW ≤ 4 | • Low risks will be maintained under review, but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe  
• These risks can be acceptable without treatment |

DETERMINING RISK ACCEPTABILITY AND THE NEED FOR ADAPTATION

Based on the outcomes of the risk analysis, it is necessary to determine and prioritize those risks requiring treatment with appropriate adaptation measures. Risk acceptability criteria need to be defined (refer to Table 8) to guide the determination of which risks are determined to be acceptable and the most significant risks requiring treatment (i.e. adaptation planning).

Often the risk evaluation is led by a project funder or leader, rather than the technical staff who led the risk analysis. Decisions on risk treatment should take into account the acceptability of external stakeholders that are likely to be affected.
Once the degree of vulnerability has been established and the most critical risks have been identified, a decision can be made regarding how to address the risks. A range of appropriate adaptation strategies are available when preparing for and adapting to climate change impacts. Selection of a strategy is dependent on a number of factors, including location, temporal scale, and the specific impacts faced.

Understanding the available resource base to implement the infrastructure activity will also be important. While some adaptation options may require little to no resources (e.g., training on monitoring) others may prove more cost-intensive.

Four generally accepted types of adaptation responses that can be implemented include: 1) accommodate and maintain; 2) harden and protect; 3) relocate; and 4) accept or abandon. These strategies can help categorize various adaptation responses for new and existing infrastructure. These strategies can help categorize various adaptation responses for new and existing infrastructure (Table 9) and understand the various advantages and disadvantages of selected responses (Table 10).

Examples of adaptive engineering design options specific to flood management infrastructure are provided in Table 11, with additional detail provided in the Annex.

**SHORT-LISTING OF ADAPTATION SOLUTIONS**

Once a range of possible adaptation options has been identified, they should be prioritized to create a shortlist of the most appropriate options for implementation. A number of approaches are available, including decisions strictly based on best judgment and not including detailed analysis and justification. Common approaches to shortlist options include the use of a Multi-Criteria Analysis (MCA) and applying an economic analysis, such as Cost-Benefit Analysis (CBA), to further refine and prepare for implementation.

An example of a completed MCA is included in the companion document: *Overarching Guide: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design.*
### TABLE 9: APPROACH TO ADAPTATION STRATEGIES

<table>
<thead>
<tr>
<th>Strategic Approach</th>
<th>Adaptation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Infrastructure</td>
</tr>
<tr>
<td>1 Accommodate and Maintain</td>
<td>• Extend, strengthen, repair or rehabilitate over time</td>
</tr>
<tr>
<td></td>
<td>• Adjust operation and maintenance</td>
</tr>
<tr>
<td>2 Harden and Protect</td>
<td>• Rehabilitate and reinforce</td>
</tr>
<tr>
<td></td>
<td>• Add supportive or protective features</td>
</tr>
<tr>
<td></td>
<td>• Incorporate redundancy</td>
</tr>
<tr>
<td>3 Relocate</td>
<td>• Relocate sensitive facilities or resources from direct</td>
</tr>
<tr>
<td></td>
<td>risk</td>
</tr>
<tr>
<td>4 Accept or Abandon</td>
<td>• Keep as is, accepting diminished level of service or</td>
</tr>
<tr>
<td></td>
<td>performance</td>
</tr>
</tbody>
</table>

### TABLE 10: ADVANTAGES AND DISADVANTAGES OF ADAPTATION APPROACHES

<table>
<thead>
<tr>
<th>Strategic Approach</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Accommodate and Maintain</td>
<td>• Less costly</td>
<td>• Requires monitoring, possibly frequent repairs, adjustments, or more</td>
</tr>
<tr>
<td></td>
<td>• More pragmatic and flexible, allows adjustment over time as more climate</td>
<td>rigorous operations</td>
</tr>
<tr>
<td></td>
<td>change data becomes available</td>
<td>• Necessitates design for more flexible or upgradeable structure</td>
</tr>
<tr>
<td>2 Harden and Protect</td>
<td>• Proactive</td>
<td>• More costly</td>
</tr>
<tr>
<td></td>
<td>• Straightforward to implement and justify</td>
<td>• Assumes reasonably accurate climate forecasts</td>
</tr>
<tr>
<td>3 Relocate</td>
<td>• Proactive</td>
<td>• More costly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Sub-optimal location may decrease period of performance or service</td>
</tr>
<tr>
<td>4 Accept or Abandon</td>
<td>• No extra up-front cost</td>
<td>• Proper communications needed to inform decision-makers and beneficiaries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to expect lower performance or service</td>
</tr>
</tbody>
</table>
### Table 11: Flood Management Infrastructure

<table>
<thead>
<tr>
<th>Climate Drivers</th>
<th>Adaptation Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level Rise, Storm Surge</td>
<td>• Consider future climate in design of coastal protection assets</td>
</tr>
<tr>
<td></td>
<td>• Beach nourishment and dune construction</td>
</tr>
<tr>
<td></td>
<td>• Revegetation of coastal areas</td>
</tr>
<tr>
<td></td>
<td>• Storm surge barriers, barrier islands, and tide gates</td>
</tr>
<tr>
<td>Extreme Precipitation Events, Flooding</td>
<td>• Consider future climate in design of asset to manage larger peak water flows</td>
</tr>
<tr>
<td></td>
<td>• Combine open space and stormwater storage to manage peak flows</td>
</tr>
<tr>
<td></td>
<td>• Provide, maintain and provide training on the use of temporary flood barriers to protect critical infrastructure</td>
</tr>
<tr>
<td></td>
<td>• Flood education, awareness and emergency management training for at risk communities</td>
</tr>
<tr>
<td></td>
<td>• Revegetation of catchments</td>
</tr>
</tbody>
</table>
Implementation of climate change adaptation programs may be defined solely as an engineering program, but will likely be part of a larger program that includes planning and zoning, government and stakeholder buy-in, and many other complex factors.

**MONITORING AND EVALUATION**

Most projects and programs include monitoring and evaluation activities that can be adjusted to cover climate change risks. If feasible, embedding climate change risks in an existing monitoring and evaluation framework is the preferred approach, rather than developing a stand-alone climate change risk monitoring and evaluation framework.

Ongoing monitoring and evaluation activities can help consistently adjust the risk assessment and management approach, and support development of risk treatments that are effective, contribute to improvements in risk understanding, detect changes in external and internal conditions, and identify emerging risks.

Monitoring and evaluation should be based on robust and simple to measure quantitative and qualitative indicators. Careful consideration should be given to the cost efficiency and ease of measurement for the proposed measures. Information can be collected and analyzed through both participatory and external evaluation. Local communities can take a very active role in monitoring tasks.

**IMPLEMENTING BEST PRACTICES**

Monitoring and evaluation provides organizations with an opportunity to identify assets susceptible to climate change impacts and better inform future asset planning. For example, asset condition deterioration profiles may change where assets are exposed to more extreme conditions.

Climate change adaptation is an emerging field, so implementation is also experimentation in some cases. Both successes and failures should be reported and documented to build a community of practice so that climate change adaptation strategies improve over time and practitioners become more conversant in implementing such strategies.
COMMUNICATION AND CONSULTATION

Climate change risk communication activities should ideally form part of the overarching outreach and communications plan for each infrastructure asset.

Communication and consultation should be integrated in all risk management activities. A robust and consistent communications plan including consideration of potential climate change risks and selected adaptation options should be developed in close collaboration with implementing partners and stakeholders. A communication plan should outline how the findings of the analysis will be made accessible to support decision making and general awareness raising for both technical and non-technical audiences.

Different target groups (e.g., government agencies, businesses, communities, and women and children) and different communication vehicles (e.g., workshops, reports, animations, summary sheets, and fact sheets) should be considered. Ongoing communication and consultation activities can support the development of appropriate objectives and understanding of the local context, help ensure that climate risks are correctly identified, and help build consensus among stakeholders on the findings of the risk assessment and the risk treatment selected for implementation.
The Kempsey Bypass Pacific Highway Assessment case study demonstrates the methodology presented in this document.

STEP 1: ESTABLISHING THE CONTEXT
The Pacific Highway is a major transport route along part of the east coast of Australia, linking Sydney, the capital of New South Wales (NSW), to Brisbane, the capital of Queensland. The Kempsey Bypass project was completed in 2013 to divert traffic around the town of Kempsey. It crosses the Macleay River and its floodplain. The corresponding Bridge, at 3.2 km (2 mi) long, is now the longest one in Australia. The benefits of the bypass are considered to be improved road safety, uninterrupted highway traffic flow, and increased reliability and better travel times.

PREFERRED ROUTE
Route options were developed through an iterative process involving a range of environmental, engineering, community, safety, and cost considerations. Eighteen feasible route options were initially developed using information gathered during community consultations and preliminary environmental investigations. The outcome of the assessment process was the development of two short-listed route options – an east and west route. The eastern alignment was considered to represent the best possible balance among social, environmental, engineering, and cost factors, while continuing to provide for the future transport needs of both the local and wider community.

FLOODING AND CLIMATE CHANGE
Specific attention was given to the proposed crossing of the Macleay River floodplain. The Macleay River has a large catchment, which can result in major flood events.

In August 1949, the river caused major flooding in the town of Kempsey and the surrounding floodplains. At least six people lost their lives, while 2,000 people were made homeless. Property damage exceeded $200M (2010 values), with the town center being washed away when 400m of the railway embankment west of Kempsey was destroyed, with 15,000 heads of cattle being lost.

Today, the town of Kempsey is protected by a scheme including levees, floodgates and flood-ways, use of natural flood storage areas, and riverbank stabilization works. A policy of buying up land in areas designated as flood plains led to many houses being transported to higher ground in recent years. A flood warning system has also been established, with rainfall stations and gauges informing about upstream river and stream levels, so as to issue flood alerts, prompt residents to protect their property, evacuate cattle and possibly people, redirect or stop traffic, ready rescue and recovery services, etc.

A legitimate concern is the impact of the new highway on flooding patterns, especially since it is a long-lived physical asset across the floodplain. Climate change is expected to increase significantly the intensity of rainfalls and thus the magnitude of floods of the Macleay River, which the highway will cross. In addition, the proximity to the coast (20km away) means that sea level rise may also impact river flood levels.

COMMUNITY INVOLVEMENT
The community and stakeholders were consulted throughout the development of the preferred route and the proposed upgrade concept design so that community concerns and ideas were appropriately incorporated into the design and assessment studies. The community’s input to the development of the concept design and environmental assessment was considerable.

Local knowledge of flood patterns, drainage issues, and emergency evacuation routes and flood refuge areas contributed to design development. Six community involvement meetings were held between 2005 and 2011.
STEP 2: CONDUCT A VULNERABILITY ASSESSMENT

Crossing both a river and floodplain exposes the highway to flooding, which would hinder traffic and the service provided by the highway. This asset would be impacted by climate change in terms of future increase in flood frequency and magnitude.

The sensitivity of the highway to flooding is Moderate to High since traffic would be stopped (thus causing loss of function or service) while erosion damage to the highway bridge and embankments is quite probable.

The overall sensitivity of the highway is moderate to high, therefore the asset is deemed to be vulnerable to extreme rainfall flooding, deserving further analysis of the risk (refer to Table 12).

<table>
<thead>
<tr>
<th>Level of Sensitivity</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NOT Sensitive</strong></td>
<td>- No infrastructure service disruption or damage</td>
</tr>
</tbody>
</table>
| **LOW Sensitivity**  | - Localized infrastructure service disruption; no permanent damage  
                      - Some minor restoration work required |
| **MODERATE Sensitivity** | - Widespread infrastructure damage and service disruption requiring moderate repairs  
                           - Partial damage to local infrastructure |
| **HIGH Sensitivity** | - Permanent or extensive damage requiring extensive repair |

Moderate or high sensitivity impacts are considered vulnerable and should be the focus of the risk assessment.

Highway under construction, and completed highway during the flooding of the Macleay River in 2013.
STEP 3: CONDUCT A RISK ASSESSMENT

Likelihood Analysis
Rainfall intensity - Climate models show that the intensity of a 40-year daily rainfall event may increase by 5 percent to 10 percent within the region by 2070, even if mean annual rainfall is projected to decrease. This may also be counter-balanced by temperature increase and dryer catchment conditions, resulting in lower runoff from rainfall.

The combination of uncertainty about projected changes in rainfall and evaporation makes it difficult to predict with confidence the likely changes to peak flows for large flood events in the MacLeay River. The NSW State Government recommends sensitivity analysis on flood modeling be undertaken to develop an understanding of the effect of various levels of change in the hydrological regime on the project.

For this project a rainfall increase of 10, 20 and 30 percent for the 100 year event was modeled, assuming parallel increases in infiltration losses of 10, 20 and 30 percent to estimate the projected change in total discharge at Kempsey (Table 13).

Consequence Analysis
Two types of impacts due to a large flood had to be considered:
1. Submersion of the highway, thus preventing traffic, possibly also causing damage and permanent loss or reduction of service on a major capital investment; and
2. Increased flooding conditions upstream around Kempsey, due to the presence of the highway embankment acting as a dam across the floodplain; consequences here could be similar if not greater to the damage of the 1949 flood (loss of lives, damage to property and houses, as well as to transportation, energy, communication and water networks, impact on economic activities, notably agriculture, etc.).

Since climate change may increase the magnitude of large floods, possible consequences should be considered as major if not catastrophic. Therefore, the risk is high to extreme and requires an adaptation strategy (Table 14).

As an example, a 16 percent runoff increase would result in an increase in peak flood level of about 0.2 meters at the bridge, thus making it more at risk for flooding.

Sea level rise - The NSW State Government guides risk analyses (notably flood risk assessments) dealing with sea level rise due to climate change to use the following projection benchmarks:
• A sea level rise of 0.4 meters by 2050; and
• A sea level rise of 0.9 meters by 2100.

For the Kempsey Bypass, the effect of the projected sea level increase by 2100 was assessed by increasing the downstream ocean level for the flood model by 0.9 meters. Modeling results indicated that the projected increase would not have a significant influence on flood levels in the study area. The projected sea level rise by 2100 is therefore not considered to present a significant issue for the project.

Likelihood of design flood - The 100-year flood event was chosen as design event (as is worldwide common practice for large transportation projects and flood studies). Since its probability of occurrence is 1 percent per year, or 63 percent in a 100-year period, the usual lifespan for large infrastructure, this event qualifies as very likely, if not nearly certain.

TABLE 13: PERCENTAGE INCREASE IN PEAK RIVER DISCHARGE AT KEMPSEY

<table>
<thead>
<tr>
<th>Increase in Rainfall Intensity</th>
<th>Increase in Infiltration Losses due to Dry Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>20%</td>
</tr>
<tr>
<td>20%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>29%</td>
</tr>
<tr>
<td>30%</td>
<td>52%</td>
</tr>
<tr>
<td></td>
<td>46%</td>
</tr>
<tr>
<td>40%</td>
<td>42%</td>
</tr>
</tbody>
</table>

TABLE 14: RISK RATING MATRIX

<table>
<thead>
<tr>
<th>LIKELIHOOD</th>
<th>CONSEQUENCES LEVEL</th>
<th>Insignificant (1)</th>
<th>Minor (2)</th>
<th>Moderate (3)</th>
<th>Major (4)</th>
<th>Catastrophic (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Certain (5)</td>
<td>MEDIUM (5)</td>
<td>MEDIUM (10)</td>
<td>HIGH (15)</td>
<td>EXTREME (20)</td>
<td>EXTREME (25)</td>
<td></td>
</tr>
<tr>
<td>Likely (4)</td>
<td>LOW (4)</td>
<td>MEDIUM (8)</td>
<td>HIGH (12)</td>
<td>HIGH (16)</td>
<td>EXTREME (20)</td>
<td></td>
</tr>
<tr>
<td>Possible (3)</td>
<td>LOW (3)</td>
<td>MEDIUM (6)</td>
<td>MEDIUM (9)</td>
<td>HIGH (12)</td>
<td>HIGH (15)</td>
<td></td>
</tr>
<tr>
<td>Unlikely (2)</td>
<td>LOW (2)</td>
<td>LOW (4)</td>
<td>MEDIUM (6)</td>
<td>MEDIUM (8)</td>
<td>MEDIUM (10)</td>
<td></td>
</tr>
<tr>
<td>Rare (1)</td>
<td>NOT SIGNIFICANT (1)</td>
<td>LOW (2)</td>
<td>LOW (3)</td>
<td>LOW (4)</td>
<td>MEDIUM (5)</td>
<td></td>
</tr>
</tbody>
</table>
STEP 4: DEVELOP AN ADAPTATION STRATEGY

Engineering Design
Using a computer flood model, a detailed assessment of flooding patterns (for the 100-yr event as well as lesser floods) was defined. Incorporating the Bypass in the model, the overall objective was to minimize changes to flooding characteristics (levels, velocities, duration) around the highway and upstream in Kempsey. Various bridge options were modeled to determine the optimum configuration to cross over the MacLeay River as well as floodways within the floodplain. A full bridging option was also considered.

These alternative bridge configurations were assessed in terms of costs, hydraulic performance and flooding impacts, as well as environmental and social considerations. Based on these, the optimum solution was determined to be a single 3.2 km floodplain bridging. The proposed highway should have no significant impact (i.e., less than 0.01 meters, within the accuracy of the model) on flood levels in the township of Kempsey and the floodplain for the projected 100 year flood. The highway will also be above submersion (with a 0.5 meters freeboard) for a 100-yr flood event.

Climate Change Adaptation
Three basic strategies were considered to manage the effects of climate change within the design life of the project:

• Design the project initially using projections for the climate-changed environment at the end of the project (i.e., design bridges and embankments using the projected 100-yr flood in 2100);

• Adapt over time to climate change by modifying project components over time (e.g., by increasing embankment heights in perhaps 40 and 80 years) and if needed, in line with climate change observations, and incorporate allowances for these potential modifications in the current design; and

• Accept the design based on current climate conditions, with the understanding that performance will be reduced by the end of the design life (i.e., that inundation might be expected more frequently over time).

Given the uncertainty surrounding the climate change projections, and the resulting effect on catchment conditions and runoff volumes, the first strategy (harden) was determined to be sub-optimal. The approach required significant capital investment at the start of the project, which might not be justified by the benefits over the useful life of the asset.

The second strategy (accommodation) was deemed preferable, as the capital expenditure to upgrade the project would be mobilized if needed. Additionally, this reflects an adaptive management approach that allows future project changes to be refined based on additional observations and projections of climate change impacts on flood frequency at the site.

STEP 5: IMPLEMENT ACTIVITY
The Kempsey Bypass was completed early 2013 and withstood the February 2013 flood of the MacLeay River as expected. Only long-time monitoring will confirm the validity of both design and climate change choices on this project.
Flood Resilience and Adaptation Guidance


General Flood Management Guidance


Coastal Flooding Guidance

FLOOD MANAGEMENT CLIMATE CHANGE ADAPTATION STRATEGIES

ANNEX

INTRODUCTION
This Annex, Flood Management Climate Change Adaptation Strategies, is a companion to Flood Management: A Methodology for Incorporating Climate Change Adaptation in Infrastructure Planning and Design. More details, including the advantages and disadvantages of various adaptation strategies, are discussed in this document. Practitioners, engineers, and other stakeholders will find the components to develop a preliminary cost estimate that is valid for a proposed project. Other aspects, such as technical feasibility and schedule, are also discussed in this Annex.

There are many comprehensive solutions and adaptation options that address climate change. Some involve technology or innovative and detailed design, while others involve the use of different materials. All options have their advantages and disadvantages, for instance: concrete is less sensitive to climate change effects, but harder to maintain. Some adaptation options may involve a substantial one-time, capital expenditure (CAPEX), whereas a number of solutions require incremental increase in normal business operational expenditures (OPEX). Nonetheless, all strategies are intended to assist with decision-making for climate-proofing flood management infrastructure. The adaptation options relevant to the following types of flood protection measures are included in this Annex: temporary, permanent, and soft.

Climate change adaptation strategies are an evolving and dynamic domain, with best practices and as-built case study examples being refined across the globe in multiple environments and contexts. This Annex is not intended to be exhaustive. If there is a strategy or approach that you think merits more discussion in this Annex, please send your ideas to climateadapteddesign@usaid.gov. We would like to consider user comments and recommendations in our next revision.
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# TABLE A.1: SANDBAGS

## Overview
Sandbags are typically used to protect small populations (ranging from villages to individual buildings) and can be found in both rural and urban areas. They generally do not require extensive capital expenditures (CAPEX) or operating expenditures (OPEX) and can often be built and maintained by local residents with local materials and without technical skills, although some instructions on how to lay the bags and where to build protection can greatly increase efficiency. They are a good complement to other flood protection measures and for protecting individual assets. Larger bags can be filled and moved by machinery to build wider structures and protect larger areas. Sandbags can be used in emergencies to protect infrastructure when flood defenses do not exist, fail, or are exceeded. Sandbags can be used for coastal and river flood events.

## Advantages
- Can be filled quickly with local materials by local residents without technical skills
- Can be used to increase the height of existing flood protection assets (i.e., existing levees or sea walls)
- Do not require significant CAPEX or OPEX
- Can successfully prevent floodwaters from entering homes and other assets
- Materials can be reused for future flood events

## Disadvantages
- Provide only temporary protection from flooding
- Can be time consuming to construct over large areas or heights
- Does not provide a long-term flooding management solution
- Can result in large quantities of waste if they require disposal (e.g., if they are exposed to polluted flood water)

## Indicative Costs
- Unlikely to require significant CAPEX / OPEX if local materials and equipment are available

## Timing for Implementation
- Protection of individual homes and assets can typically be achieved in less than one day
- Sandbags are typically more suitable for flood events where significant warning time can be provided to communities (i.e., river flooding in large watersheds)

## Governance
- Flood protection measures constructed from sandbags do not require government involvement; however, government involvement can significantly contribute to the success of flood protection by preparing fact sheets and awareness materials and by providing equipment and trained staff to assist in the construction

## Acceptability
- Typically highly acceptable to local communities and governments for temporary flood protection in extreme flood events

## Feasibility and Technical Requirement
- No specific engineering input is required for design or construction
- Sandbags can often be built and maintained by residents with local materials and without technical skills. Large sandbags may require the use of machinery
- Sandbags are not suitable for long-term flood protection
### TABLE A.2: OTHER TEMPORARY FLOOD BARRIERS

#### Overview

Temporary flood barriers can be constructed from either proprietary products or earth bunds (retaining walls). Temporary flood barriers constructed with local materials and equipment generally do not require significant CAPEX. Temporary flood barriers can be constructed seasonally (i.e., before the wet season). Temporary flood barriers can provide adequate flood protection against extreme flood events and protect infrastructure when other permanent flood defenses are exceeded. They can also provide flood protection against coastal and river flood events. The use of temporary flood protection measures are most suitable for river flood events where sufficient warning can be provided to enable enough time to construct them prior to flood peaks.

#### Advantages

- Do not require extensive CAPEX to design and construct earth bunds
- Can be used to increase the height of existing flood protection
- Assets including levees
- Can be constructed with local materials by local residents without technical skills
- Materials can be reused for future flood events

#### Disadvantages

- Extensive CAPEX for proprietary flood barriers
- Provide only temporary protection from flooding
- Can be time consuming to construct over large lengths and heights
- Does not provide a long-term flooding management solution
- Higher risk of failure when compared to compared to formally constructed levees

#### Indicative Costs

- Unlikely to require significant CAPEX / OPEX if local materials and equipment are available
- Proprietary flood barriers typically require significant CAPEX / OPEX to purchase and train people to install and remove

#### Timing for Implementation

- Flood protection of individual homes and communities can typically be achieved in days
- Temporary flood barriers are typically more suitable for flood events where significant warning time can be provided to communities, i.e., river flooding in large watersheds

#### Governance

- Temporary flood barriers do not require involvement from government; however, government can significantly contribute to the success of the flood protection by providing materials, equipment and trained staff to assist in construction

#### Acceptability

- Typically highly acceptable to local communities and government for temporary flood protection in extreme flood events

#### Feasibility and Technical Requirement

- No specific engineering input is required for design or construction
- They can often be built and maintained with local materials and without technical skills
- Proprietary flood barriers may require specific training to install and remove
- They are not suitable for long-term flood protection
## TABLE A.3: BREAKWATERS, SEA WALLS, DIKES AND REVETMENTS

### Overview

Breakwaters, sea walls and dikes are onshore structures with the key function of protecting low-lying coastal areas, human habitation, and infrastructure against coastal flooding from waves, unusually high tides, storm surge, and in some cases tsunami. Revetments are onshore structures with the key function of protecting the shoreline from erosion due to storm surge and waves. Breakwaters, sea walls, dikes typically require extensive CAPEX to construct and maintain.

Sea walls can also provide flood protection from sea level rise. Sea walls typically work by reflecting the impact of waves back into the sea and reducing the wave impact behind the wall. Raising existing sea walls can be an easier approach to reduce flooding impacts associated with sea level rise and storm surge. When designing new infrastructure, consideration should be given to enabling the height of the asset to be increased in future as the sea level rises.

### Advantages

- Protection of coastal areas from waves, storm surge, high tides or sea level rise, depending on the measure selected
- Avoids the need to either relocate communities or elevate homes to provide flood protection
- May provide protection against coastal erosion

### Disadvantages

- High CAPEX is typically required to construct breakwaters, sea walls, dikes or revetments
- May result in significant environmental impact in coastal environments.
- May transfer erosion or flood risk further down the coast
- Construction of breakwaters, sea walls, dikes and revetments could potentially worsen of river flooding if not designed and constructed correctly (e.g. not allowing river flood waters to drain to the sea)

### Indicative Costs

- High CAPEX is usually required

### Timing for Implementation

- The design and construction typically takes a long time to complete (several years)

### Governance

- Construction of breakwaters, sea walls, dikes, and revetments will typically require government involvement, CAPEX funding, and ongoing maintenance

### Acceptability

- These measures are highly acceptable to local communities and governments for flood protection measures against coastal flooding events, although there might be some opposition from downstream communities, due to potential impacts of erosion and accretion, as well as concerns related to environmental impacts

### Feasibility and Technical Requirement

- Engineering involvement is typically required to design and construct breakwaters, sea walls, dikes, and revetments
- Local materials, equipment, and workers may be used during construction
### TABLE A.4: ARTIFICIAL REEFS AND DETACHED BREAKWATERS

**Overview**
Detached breakwaters and artificial reefs are near-shore structures designed to reduce beach erosion. They are typically built parallel to the shoreline. Detached breakwaters will not typically provide flood protection from storm surge events or sea level rise but may provide some limited protection from tsunami events by reducing wave energy. Detached breakwaters and artificial reefs will typically require extensive CAPEX to construct. Constructing artificial reefs and detached breakwaters is a proven method to minimize the impacts of storm surge on coastal erosion, which can help reduce long term coastal flooding through reduced erosion rate.

<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reduced beach erosion</td>
<td></td>
</tr>
<tr>
<td>• Reduced wave heights</td>
<td></td>
</tr>
<tr>
<td>• Some limited flood protection may be provided for tsunami events</td>
<td></td>
</tr>
<tr>
<td>• May promote marine life by providing habitat</td>
<td></td>
</tr>
<tr>
<td>• Multiple detached breakwaters spaced along the shoreline can provide protection to substantial shoreline frontages</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Disadvantages</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Extensive CAPEX required to construct</td>
<td></td>
</tr>
<tr>
<td>• Detached breakwaters and artificial reefs do not provide flood protection against storm surge and sea level rise</td>
<td></td>
</tr>
<tr>
<td>• May block ship passage</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Indicative Costs</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Extensive CAPEX may be required to construct detached breakwaters and artificial reefs but will depend on the availability of local materials and equipment</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Timing for Implementation</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• The design and construction of breakwaters typically take a long time to complete</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Governance</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Construction of detached breakwaters and artificial reefs will typically require government involvement, CAPEX funding and ongoing maintenance</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Acceptability</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• These measures are highly acceptable to local communities and governments for reducing beach erosion and promoting marine life</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Feasibility and Technical Requirement</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Detached breakwaters and artificial reefs do not provide flood protection against sea level rise and storm surge</td>
<td></td>
</tr>
<tr>
<td>• Engineering is typically required to design and construct detached breakwaters and artificial reefs</td>
<td></td>
</tr>
<tr>
<td>• Local materials, equipment and workers may be used during construction</td>
<td></td>
</tr>
</tbody>
</table>
# TABLE A.5: BEACH NOURISHMENT AND DUNE CONSTRUCTION

## Overview

Beach nourishment and dune construction are used to prevent shoreline erosion by placing material such as sand or gravel in eroded areas of the beach. A wider beach can reduce storm damage to coastal structures by dissipating wave energy across the surf zone.

An essential component of dune reconstruction is planting of vegetation and placement of netting or snow fencing to help retain sand. Beach nourishment and dune construction typically involve extensive CAPEX to construct and OPEX to maintain.

## Advantages

- Prevents shoreline erosion in coastal areas
- Establishes a more natural solution than other methods
- Lower CAPEX than physical engineered flood mitigation solutions such as sea walls
- Minimizes environmental impacts on coastal areas

## Disadvantages

- Ongoing maintenance (OPEX) is required to ensure the required level of service is achieved
- Beach nourishment and dunes do not provide flood protection from sea level rise and storm surge. Their primary objective is to prevent shoreline erosion
- Design life of these solutions is less than that of other options such as sea walls and levees. Beach renourishment can be easily eroded

## Indicative Costs

- Extensive CAPEX may be required to construct beach nourishment and dune construction measures but will depend on the availability of local materials and equipment
- Extensive OPEX may be required for ongoing maintenance of these measures

## Timing for Implementation

- The design and construction of beach nourishment and dunes typically takes a long time period to complete

## Governance

- Construction of beach nourishment and dunes will typically require government involvement, CAPEX funding, ongoing maintenance

## Acceptability

- Moderately acceptable to local communities and governments; however there can be concerns about short term nature of the solution

## Feasibility and Technical Requirement

- Beach nourishment and dunes do not provide flood protection against sea level rise or storm surge
- Engineering expertise is required to design and construct these measures. Local materials, equipment and workers may be used during construction
<table>
<thead>
<tr>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm surge barriers are constructed to protect estuaries against storm surge flooding. Typically the barrier consists of a series of movable gates that under normal conditions stay open to allow for water flow; but the gates are closed when storm surges exceed a certain level. Barrier Islands are comprised of a series of coastal islands, which are constructed parallel to the coast line to protect the shoreline against storm surge events. Tide gates can be used to protect low-lying coastal areas from inundation from high tides. They can provide protection from coastal flooding. Storm surge barriers and barrier islands are typically suitable for providing flood protection only from storm surge events. They are not designed to provide protection against permeant inundation from sea level rise.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
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</thead>
<tbody>
<tr>
<td>• Storm surge barriers and barrier islands can protect coastal areas from storm surge events</td>
</tr>
<tr>
<td>• Tide gates can protect coastal areas from tidal inundation</td>
</tr>
<tr>
<td>• Coastal erosion is reduced</td>
</tr>
<tr>
<td>• Power generation may be achieved from tide gates if they are constructed as tidal barriers with turbines</td>
</tr>
<tr>
<td>• May promote marine life by providing habitat</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Does not provide protection against sea level rise</td>
</tr>
<tr>
<td>• Extensive CAPEX required to construct and operate</td>
</tr>
<tr>
<td>• Barriers could create environmental impacts associated with changing coastal ecosystems</td>
</tr>
<tr>
<td>• River flooding near the coast could be exacerbated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indicative Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Extensive CAPEX required</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Timing for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The design and construction typically takes several years to complete</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Governance</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Construction typically requires government involvement including approvals, CAPEX funding, and ongoing OPEX funding for operation and maintenance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>• These methods are highly acceptable to local communities for preventing flooding from storm surge events and minimizing coastal erosion, but government acceptability may be low due to environmental impacts associated with changing coastal ecosystems during construction and operation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feasibility and Technical Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Engineering is typically required to design and construct storm surge barriers, barrier islands and tide gates</td>
</tr>
<tr>
<td>• Construction materials, equipment and skilled workers are typically required to be used during construction</td>
</tr>
</tbody>
</table>
### TABLE A.7: LEVEES

#### Overview

Levees usually consist of earth construction. They are typically constructed parallel to a river or low-lying coastal area, and are used to regulate flood levels. A ring levee may be constructed around villages in large floodplains.

Levees are designed to protect against a defined storm event, or storm event with an accepted probability of occurrence (e.g. 500yr storm or .05% annual exceedance probability. There will always be the risk that the levee will be overtopped by a flood event greater than the design storm.

Levees are usually considered secondary to non-structural measures like development controls (i.e., flood planning levels). Levees can be expensive to construct and maintain; they encourage development of flood-prone land; and they increase flood depth outside of the levee. If a levee fails, the damage can be greater than that of a natural flood event due to the increased development in the protected area.

Levees are a solution as protection against coastal and river flood events.

#### Advantages

- Protect coastal areas, floodplains, and urban areas from river flooding, tidal inundation, storm surge or sea level rise
- Avoid the need to relocate communities, elevate homes or provide flood protection of buildings
- Protection is provided for flood events up to a defined design recurrence interval (i.e. design storm)
- May increase the area of developable land
- Small levees can be inexpensive to construct

#### Disadvantages

- Extensive CAPEX / OPEX is typically required to construct and maintain large levees
- May result in significant environmental impacts
- Encourage development of flood-prone land
- Increase the depth, velocity and inundation extent of floodwaters outside the protected area
- May result in extensive flood damages if they fail due to increased development in protected areas
- Could transfer flooding impacts elsewhere, for example, further downstream

#### Indicative Costs

- Extensive CAPEX / OPEX is typically required to construct and maintain large levees
- Small levees can be built with limited costs if they require only local labor, local materials

#### Timing for Implementation

- The design and construction of large levees typically takes a long time period
- Small levees can be built in a matter of days

#### Governance

- Construction of large levees will typically require government involvement and CAPEX / OPEX funding for construction and ongoing maintenance
- Small levees often protect only individual houses or small part of the communities

#### Acceptability

- These measures are highly acceptable to local communities and governments for flood protection measures

#### Feasibility and Technical Requirement

- Engineering is typically required to design and construct levees
### TABLE A.8: FLOOD MITIGATION DAMS

#### Overview
Flood mitigation dams reduce peak flood discharges in watercourses downstream of the dams. As runoff generated by a storm event passes through a flood mitigation dam, the dam will progressively fill the area upstream of it, trapping a portion of the flood flow; though over-topping may occur. The outlet structures (e.g. flood gates) may be configured to adjust the rate of release from the flood mitigation dam.

For flood mitigation dams to be effective, it is essential that adequate space be retained in the impoundment area to store flood water when a flood occurs. This may preclude, or present operational management challenges when the flood mitigation dam has a dual use such as town water supply or irrigation storage. Flood mitigation dams are suitable to provide increased flood protection against river flood events.

#### Advantages
- Reduce peak flood discharges in watercourses downstream of the dam
- Reduce peak flood levels, depths, velocity and hazard in watercourses downstream of the dam
- May reduce the size of other flood infrastructure needed, such as downstream floodways
- May increase the area of developable land
- May be used to provide water storage for town water supply or irrigation in conjunction with mitigating flood flows. This dual use, although not ideal from a flood mitigation perspective, may be required to gain adequate CAPEX funding for construction

#### Disadvantages
- Extensive CAPEX / OPEX is typically required to construct and maintain flood mitigation dams
- It may be difficult to find a suitable location for the dam wall that captures a suitable number of upstream tributaries
- The mitigating effect will be insignificant if the dam impoundment area is full or partly full at the start of the flood event
- May result in extensive flood damages if dam fails, possibly greater than that of a natural flood event
- May result in significant environmental impacts
- May lead to community misperception that flooding will not occur downstream of the dam in the future

#### Indicative Costs
- Extensive CAPEX / OPEX is typically required to construct and maintain flood mitigation dams

#### Timing for Implementation
- The design and construction of flood mitigation dams typically takes several years

#### Governance
- Construction of flood mitigation dams will almost certainly require government involvement and CAPEX / OPEX funding

#### Acceptability
- Moderately acceptable to local communities and governments currently affected by flooding, due to environmental and land use conflicts
- This type of measure can result in significant opposition if relocation is required for some communities or if it will alter the flood patterns and water availability of downstream and upstream communities

#### Feasibility and Technical Requirement
- Engineering involvement is required to design, construct and operate flood mitigation dams
TABLE A.9: STORMWATER MANAGEMENT - RETENTION AND DETENTION BASINS

Overview

A retention or detention basin is a small dam that provides temporary flood storage to reduce peak flood discharges in watercourses downstream of the basin. Retention basins are commonly used to reduce post-development peak flows to the level of pre-development peak flows for urban developments. The basins vary from small to large structures, the former being more properly regarded as flood mitigation dams.

A retention or detention basin behaves in the same way as a flood mitigation dam. As the flood event passes through the basin, the storage will progressively fill, trapping a portion of the flood volume. Retaining basins are commonly used to manage stormwater runoff from development that increases runoff generation. Basins provide flood protection and channel erosion protection during storm events.

Silt and debris from runoff can be captured in basins. Maintenance is required to ensure the design capacity of the basin is maintained.

Advantages

- Reduce peak flood discharges in watercourses downstream of the retaining basin
- Reduce peak flood levels, depths, velocity and hazard in watercourses downstream of the retaining basin
- May reduce the size of other flood infrastructure needed, such as downstream floodways
- Can be designed to provide environmental habitat

Disadvantages

- Extensive CAPEX / OPEX is typically required to construct and maintain retaining basins
- It may be difficult to find a suitable location for the retaining basin embankment that captures a suitable number of upstream tributaries
- May result in significant environmental impacts
- May lead to community perception that flooding will not occur downstream of the retarding basin embankment in the future
- May increase stream erosion downstream of the retarding basin, due to increased time to release the peak flow
- Substantial area is required to achieve the required flood mitigation storage
- Provides little attenuation effect when over-topping occurs

Indicative Costs

- Extensive CAPEX / OPEX is typically required to construct and maintain retaining basins

Timing for Implementation

- The design and construction of retaining basins typically takes up to one year

Governance

- Construction of retarding basins will typically require government approval (permitting) and CAPEX / OPEX funding

Acceptability

- High acceptability by local communities and government

Feasibility and Technical Requirement

- Engineering involvement is required to design and construct retarding basins
### TABLE A.10: CHANNEL MODIFICATIONS

#### Overview
The hydraulic capacity of a channel to convey floodwater can be increased by widening, deepening or re-aligning the channel. Capacity can also be increased by clearing the channel banks and bed of obstructions to the flow, such as dense riparian vegetation. In urban areas, channel modifications can provide the community with other positive outcomes, such as enhanced visual aesthetics from the landscaping; however, this may result in an increased flood hazard to the community. Channel modifications are likely to be most effective on steeper streams with overgrown channel vegetation and narrow floodplains. Channel modifications are unlikely to have a significant effect when there are extensive areas of overbank flooding or when there is coastal flooding. The use of concrete-lined channels to replace natural streams is particularly undesirable from an environmental perspective. However, the use of concrete can be effective in stabilizing banks when combined with natural restoration of stream bed.

#### Advantages
- Increase the capacity of channels to convey flood waters
- Could reduce the extent of flooding in overbank floodplain regions
- May enhance visual aesthetics in urban areas by incorporation of landscaping
- Channel modification could be undertaken with a low CAPEX

#### Disadvantages
- Could result in higher flood hazard to community, due to increased flood depths and velocity in channels
- May be suitable only for overgrown channels in small floodplains
- Are not suitable for mitigating the impacts of coastal flooding
- May result in environmental impacts
- Could accentuate downstream flooding impacts
- Require ongoing maintenance
- Reduced channel stability

#### Indicative Costs
- Channel modifications could be undertaken with a low CAPEX, but ongoing OPEX may be required for channel maintenance, such as pruning vegetation

#### Timing for Implementation
- The timing for implementation is influenced by the method used to modify channels
- Clearing dense vegetation could be undertaken in a relatively short period of time; however, replacing a vegetated channel with a concrete-lined floodway may take a long time to construct

#### Governance
- Channel modification works may require government involvement and CAPEX / OPEX funding for construction and ongoing maintenance

#### Acceptability
- Acceptable to local communities and governments for flood mitigation; however, they may result in undesirable environmental outcomes

#### Feasibility and Technical Requirement
- Engineering may be required to design and construct channel modifications; however, measures such as clearing dense channel vegetation may not require engineer involvement
### TABLE A.11: REVEGETATION

#### Overview

The removal of forest and other natural cover, along with the conversion of land to agricultural uses, increases the potential for runoff from rainfall events, leading to higher flood levels. Deforestation and other land-use practices can also lead to greater incidences of landslides and mud flows (UN, n.d.). Revegetation of upper watersheds can reduce peak flood flows in downstream waterways, reducing flood impacts. Potential increases in flood magnitudes from climate change impacts can also be reduced by a combination of floodplain and wetland restoration where possible. This flood mitigation option is a holistic approach to watershed management and differs from other approaches to flood protection and mitigation, which often do not go beyond the individual asset or community it is designed to protect. A similar holistic approach can be adopted to re-vegetate the coastline, thereby reducing risks of coastal erosion and coastal flooding. Revegetation is suitable to increase flood protection against river, torrential, and coastal flood events.

#### Advantages

- Reduced peak flows to downstream waterways
- Can reduce downstream flood impacts such as inundation extent, level, depth, and velocity
- Significant beneficial environmental outcomes
- Can reduce waterway or coastal erosion
- May delay, or avoid, the need to upgrade existing flood protection measures in downstream reaches
- Could recharge groundwater resources
- Improvement of water quality
- Holistic approach to watershed management

#### Disadvantages

- Extensive CAPEX / OPEX is usually required for revegetation program and ongoing management
- Could result in a reduction of land available for agricultural use
- May result in land ownership conflicts if revegetation is required on private land
- Management of other natural disasters such as wildfires may be required

#### Indicative Costs

- Extensive CAPEX / OPEX is usually required for revegetation program and ongoing management

#### Timing for Implementation

- Revegetation of upper watersheds takes a long time to implement and may require ongoing irrigation until vegetation becomes established
- The full benefits of revegetation might not be realized for a decade after initial establishment of the revegetation program

#### Governance

- Government involvement will typically be required to address land ownership issues and relocation of existing communities and assets

#### Acceptability

- Low acceptability is likely if communities are impacted negatively by revegetation measures unless there is a payoff system in place
- Acceptability can also be high if the community is involved and there are no impacts on current livelihood or production systems

#### Feasibility and Technical Requirement

- May be suitable only in upper watersheds which contain no major assets, villages or extensive agricultural regions
- More suitable to undeveloped land used for agricultural use
**TABLE A.12: SOAK PITS**

**Overview**

Soak pits are buried chambers that allow stormwater flows to soak into the ground or into unconfined aquifers. Soak pits typically comprise a trench containing gravel; they provide disposal of stormwater flows and in some cases, stormwater treatment. Soak pits are applicable only in regions with permeable soils such as fast-draining gravel and sand subsoil profiles. Soak pits can comprise small devices, such as those for a single house, or large devices suitable for rapid infiltration of stormwater overland flows (MoE, 2004).

**Advantages**

- Provide a means to dispose of stormwater flows
- Could reduce the magnitude of surface overland flows discharging into watercourses, providing water quality benefits
- Increase groundwater recharge
- Can be used in flat terrain where it is difficult to construct overland flow paths with a suitable grade
- Typically require a small footprint
- Low CAPEX is required to construct local soak pits
- Prevent erosion of watercourses from large stormwater flows

**Disadvantages**

- Requires permeable soils
- Not suitable in areas with high groundwater tables
- Could result in contamination of groundwater if pre-treatment is not undertaken to reduce sediment loads
- Sediment loads may result in blockage of piped infrastructure
- Require appropriate topography to prevent slope instability
- Maintenance of filter material may be required to ensure the design life of service is achieved
- May result in local flooding if clogging of soak pits occurs due to insufficient maintenance
- Significant CAPEX may be required to construct large-scale rapid soak pits

**Indicative Costs**

- Low CAPEX is required to construct local soak pits; however, significant CAPEX may be required to construct large-scale rapid soak pits

**Timing for Implementation**

- Constriction of soak pits does not typically take a long time; however, investigations of the suitability of in-situ soils for soak pits will take some additional time

**Governance**

- Construction of soak pits may require government approval through the typical permitting process for stormwater management structures

**Acceptability**

- High acceptability by local communities and government

**Feasibility and Technical Requirement**

- Soak pits are suitable only for regions with native soils with high infiltration rates. Engineering expertise is required to design and construct soak pits, in particular investigation of the suitability of native soils for infiltration of stormwater flows
### TABLE A.13: BYPASS FLOODWAY

#### Overview
Bypass floodways redirect a portion of floodwaters away from areas impacted by flooding and therefore reduce flood depths and velocities downstream of the diversion. Bypass floodways can be used in urban or rural locations and may comprise floodways, canals, overland flow paths (refer to Table A.16). Opportunities for the construction of bypass floodways are typically limited by existing development, topography, availability of land and environmental constraints. Bypass floodways may exacerbate downstream flood impacts due to directing flows away from the natural watercourse location (DIPNR, 2005). Bypass floodways may be a suitable method to divert increased flood flows resulting from climate change around existing villages and assets. They can provide protection from urban and river flooding.

#### Advantages
- Reduce peak flood levels, depths, velocity and hazard downstream of the diversion
- Reduce flood risk to assets and residents by diverting flows away from assets, homes and residents
- May reduce the size of other flood infrastructure needed, such as downstream floodways
- May increase the area of developable land

#### Disadvantages
- Extensive CAPEX / OPEX may be required to construct and maintain bypass floodways
- Opportunities to construct bypass floodways may be limited by the existing development, topography, availability of land, and environmental constraints
- Bypass floodways may exacerbate downstream flood impacts by directing flows away from the natural watercourse
- May impact channel both upstream and downstream of the diversion

#### Indicative Costs
- Extensive CAPEX / OPEX is typically required to construct and maintain bypass floodways but costs will depend on the scale of the design and the availability of local materials and equipment

#### Timing for Implementation
- The design and construction of bypass floodways typically takes a long time, but will depend on the size of the bypass floodway and availability of equipment and skilled workers

#### Governance
- Construction of bypass floodways may require government involvement and CAPEX / OPEX funding for construction and ongoing maintenance

#### Acceptability
- Typically this is highly acceptable to local communities and governments for flood mitigation

#### Feasibility and Technical Requirement
- Engineering involvement is required to design and construct bypass floodways
## TABLE A.14: OVERLAND FLOW PATHS

### Overview

Overland flow paths provide a path to convey stormwater when the primary means of stormwater conveyance is exceeded. For example when there is no piped stormwater network or a piped stormwater network is overwhelmed by a flood event larger than it was designed to convey. Overland flow paths are commonly used in urban areas to convey stormwater flows exceeding the capacity of the piped stormwater network and typically consist of road pavements, culverts and swales.

Overland flow paths are typically located at ground level but may also comprise large buried conduits and stormwater inlet structures. The protection of stormwater overland flow paths from development is required to minimize flooding of assets and homes during extreme flood events.

### Advantages

- Provide a means to convey stormwater flows away from assets, homes and residents
- Reduce the CAPEX required to construct the primary stormwater network, such as pipes and pits
- Stormwater overland flow paths are less likely to be blocked than closed conduit stormwater networks
- Can use existing infrastructure such as roads to convey stormwater using the curb and gutter
- Can quickly convey stormwater away from assets and homes which therefore reduces the duration of flood related impacts

### Disadvantages

- Extensive CAPEX is required to construct stormwater overland flow paths
- Could create a flood hazard to the community
- Could transfer flooding impacts elsewhere, such as further downstream
- Could increase waterway erosion
- Typically do not provide any flood attenuation capacity
- Difficult to retrofit existing development

### Indicative Costs

- Extensive CAPEX may be required to construct overland flow paths; however, the CAPEX varies significantly due to the surface treatment and the availability of local materials, equipment and resources to complete the work. For example, construction of overland flow paths on sealed road pavements will be significantly more expensive than vegetated swale drains

### Timing for Implementation

- The design and construction of overland flow paths is typically undertaken during construction of urban developments

### Governance

- Construction of overland flow paths may require government assistance; however, the construction of small-scale overland flow paths may be constructed with local materials, equipment and personnel. To maintain their effectiveness, overland flow paths need to be supported by planning controls

### Acceptability

- Construction of overland flow paths may require government assistance; however, the construction of small-scale overland flow paths may be constructed with local materials, equipment and personnel

### Feasibility and Technical Requirement

- Overland flow paths are highly suitable for use in urban watersheds. Engineering involvement may be required to design and construct overland flow paths depending on the scale of the works
### TABLE A.15: WATER PROOFING BUILDINGS

#### Overview

Waterproofing a building involves the use of water resistant materials in the design and construction of a building to minimize structural damage, and possibly damage to its contents, in the event of a flood.

To prevent or minimize structural damage from flooding, buildings should be designed and constructed to withstand inundation, debris, and buoyancy forces. While preventing flooding of buildings should be a higher priority, waterproofing of structures will minimize damages should flooding occur. Waterproofing buildings is suitable to provide increased flood protection of properties against coastal and river flood events.

#### Advantages
- Prevents or minimizes flood damage to buildings and possibly building contents
- Residents and businesses can remain in their current locations
- Lower CAPEX than large-scale flood protection measures such as levees

#### Disadvantages
- Not all materials are suitable for flood proofing of buildings
- Flood hazard and property access issues are not mitigated
- Generally suitable only in low frequency flood hazard areas

#### Indicative Costs
- Significant CAPEX may be required to protect a large number of buildings; however, individual buildings may be able to be protected with little CAPEX by using local materials, equipment and workers
- The CAPEX will depend on the scale and design of buildings

#### Timing for Implementation
- Individual buildings can be water proofed in a period of months; however, protecting a large number of buildings may take up to several years

#### Governance
- Water proofing individual buildings may not require involvement from government
- Government approvals may be required to construct a water proofed buildings in regions where development, should not be encouraged for example, i.e., floodplains and super-deltas

#### Acceptability
- Typically acceptable to local communities and government when it is not possible to remove buildings from the flood risk
- Generally low CAPEX is required, increasing the acceptability of such measures

#### Feasibility and Technical Requirement
- The feasibility of waterproofing buildings depends on the style of housing construction, the number of buildings to be protected, and the availability of local materials, equipment, and trained workers
### Table A.16: Elevation of Dwellings (And Other Vertical Structures)

**Overview**

Elevating, lifting or moving a house is a suitable flood mitigation measure in low frequency flood hazard areas. Significant CAPEX may be required to elevate a large number of homes, and not all houses are suitable for elevation. House elevation can be incorporated in land use planning or specifications for new development. House elevation can provide adequate flood protection of properties against coastal and river flood events. Assets other than individual houses can also be elevated to be protected from flood water; these include water pumps, food shelters, power generators, etc. Note that in high frequency flood hazard areas, physical means of flood protection such as levees are typically required.

**Advantages**

- Lower CAPEX than for large-scale flood protection measures such as levees
- Residents can remain in their homes and locations
- Reduced flood damage to assets
- Houses most suitable for elevation are timber framed and clad with non-masonry or stone materials. These house styles are common in developing countries

**Disadvantages**

- Suitable only in low flood hazard areas
- Does not provide a physical means of flood protection, but rather reduces flood damages
- Not all houses are suitable for elevating. Houses of brick or stone construction, or with slab-on-ground are typically too difficult, or expensive, to elevate
- Residents in elevated houses can become isolated for long periods during flood events. This may increase the needs placed on emergency services personnel

**Indicative Costs**

- Significant CAPEX may be required for a large number of homes
- CAPEX depends on the style of housing construction. Changing from slab-on-ground to pier-on-joint, or pier and beam design can increase construction costs by around 10 percent for a new house

**Timing for Implementation**

- An individual house can be elevated in a short time period; however, elevating a large number of houses may take longer to complete

**Governance**

- Elevating individual houses may need to consider local permitting or height restrictions. Flood planning levels, or elevations, would be very beneficial

**Acceptability**

- Typically highly acceptable to local communities and governments due to the low CAPEX generally required to elevate houses in developing countries; however, the funding of the work largely influences the acceptability

**Feasibility and Technical Requirement**

- The feasibility depends on the style of housing construction, the number of houses to be elevated, and the availability of local materials, equipment and trained workers
### TABLE A.17: LAND USE PLANNING

#### Overview

Physical flood protection and mitigation measures are increasingly seen as secondary options to non-structural measures such as development controls. Land use planning at the local or municipal level can be a useful tool in reducing future flood damages. The best way to reduce future flood damages is to prevent development from occurring on flood-prone land.

Zoning of land and setting flood planning levels are an effective approach but should be coupled with broader land use planning objectives so the land has a defined use (UN, n.d.). Land use planning will typically consider issues such as peak flow management, waterway stability, water quality, and emergency response to extreme flood events. A common method of land use planning involves setting flood planning levels (minimum floor elevation standards) for which land development must be constructed at higher levels. These flood plains will typically correspond to a flood event of a specified return period. Flooding and damages will still occur when flood event magnitudes exceed flood planning levels (unless the Probable Maximum Flood events (PMF) is adopted for the flood planning level).

Land use planning measures are relevant for all coastal and river flooding events.

#### Advantages

- Reduces the likelihood of building flooding and associated damages to an acceptable level
- Ensures development is not constructed in areas prone to flooding
- Reduce emergency services involvement during floods
- Reduced duration of flooding

#### Disadvantages

- Reduces the area of land available for development
- May require expensive mitigation measures to elevate land or structures above the specified flood planning level
- Could create the perception that the flood planning level defines the maximum limit of flooding
- Extreme flood events can exceed the flood planning level

#### Indicative Costs

- Low CAPEX typically is required to determine flood planning levels however, mitigations measures to facilitate construction above this level may require extensive CAPEX

#### Timing for Implementation

- Significant time may be required to determine appropriate land use planning objectives and flood planning levels

#### Governance

- Determining flood planning levels and appropriate land use planning objectives will typically require government assistance

#### Acceptability

- Moderate acceptability by local communities and government; flood insurance may be required for properties within the flood zone

#### Feasibility and Technical Requirement

- Highly suitable to minimize flood impacts from coastal and river flood events
- Engineering involvement and detailed flood studies are required
## TABLE A.18: COMMUNITY RELOCATION

### Overview

In certain areas it may be impractical or uneconomical to provide flood protection or mitigation to existing homes and assets at risk. This may occur in regions of high flood hazard or where the construction of physical flood protection measures is not viable. Relocation is often considered for communities living on very low-lying coral atolls (e.g., in the Indian Ocean and South Pacific). In these circumstances, it may be appropriate to relocate properties and assets away from the potential flood hazard. Extensive CAPEX is required to relocate communities, given that in addition to the cost of relocating houses, it will be necessary to construct public assets such as roads and utility services.

In some instances, it may require less CAPEX to relocate an entire village than to construct a physical flood protection measure such as a levee. Relocating communities away from areas influenced by coastal and river flood events would remove the associated flood risk to properties and prevent the need to construct flood protection or mitigation measures. Relocation generally requires a long term engagement process both for the community being relocated and for the community that is to accept them.

When planning a relocation, consideration needs to be given to what will be done with existing assets including buildings, roads and utilities. Will they be removed and the land remediated, or will they be abandoned, if so what will be the social and environmental impacts?

| **Advantages** | • Reduce, or completely remove, the risk of flooding to properties and residents  
| | • Reduce on-going CAPEX / OPEX associated with repairs to flood damaged assets  
| | • Reduce risk to emergency services personnel during flood emergencies |

| **Disadvantages** | • Extensive CAPEX may be required to relocate large communities and construct new public assets such as roads and utility services  
| | • There can be very strong opposition to relocation  
| | • Residents may become disconnected from their families and places of work, which could result in loss of income or loss of access to food and water |

| **Indicative Costs** | • Extensive CAPEX is likely required to relocate communities and build new public assets. There will also be costs associated with the removal of abandoned supporting infrastructure and associated remediation |

| **Timing for Implementation** | • Individual houses can be relocated in a short time period; however, relocating an entire community is likely to take several years |

| **Governance** | • Relocating individual houses may not require involvement from government; however, relocating large communities will typically require government assistance and a long term engagement process |

| **Acceptability** | • Unlikely to result in widespread acceptability in the community due to potential disconnection from family, work, and in some cases significant cultural ties (e.g., burial sites)  
| | • Homeowners generally have strong sentimental and emotional attachment to their properties and communities and may oppose relocation |

| **Feasibility and Technical Requirement** | • The feasibility of relocating an entire community depends on the number of houses to be relocated, the new assets that may be required, and whether physical flood protection measures can be constructed at the current location with a lower CAPEX  
| | • Relocation will require detailed planning and engineering studies which should include remediation of the area being abandoned |
### TABLE A.19: FLOOD FORECASTING AND WARNING

#### Overview

The operation of a flood warning and response system is the most effective method for reducing the risk of loss of life and economic losses. A number of low-cost solutions could be used at the village level to enable local populations to foresee a coming flood. Communication methods including wind-up radios and translation of forecast products have helped farmers reduce the impact of climate related hazards.

A flood forecasting and warning system must provide sufficient lead time for communities to respond. Increasing lead time increases the potential to lower the level of flood damages and loss of life. Appropriate measures of warning the community are also required so flood warnings can reach as many people as possible. An appropriate flood forecasting and warning system involves numerous components; however, a hydro-meteorological network is the key requirement for most flood prediction and warning systems. In particular, precipitation and stream flow data are needed (UN, n.d.). Flood forecasting and warning are very relevant for river and coastal flood events.

#### Advantages

- Can provide sufficient lead time for communities to respond to extreme flood events
- Increasing lead time increases the potential to lower the level of flood damages and loss of life from flood events
- Data collected from the hydro-meteorological network can be used to improve the accuracy of flood modeling tasks
- The system can also be used to provide information on water availability leading to reduced water conflict and optimal water usage

#### Disadvantages

- Extensive CAPEX is required to develop a flood prediction and warning system
- Ongoing OPEX is required to operate the flood prediction and warning system and maintain the hydro-meteorological network
- Trained forecasters are required to operate the system
- Need an appropriate warning communication system to be effective
- Flood education is also required for the system to be successful. People need to know what to do when a warning is given

#### Indicative Costs

- Extensive CAPEX / OPEX is required to construct, maintain, and operate flood forecast and warning systems

#### Timing for Implementation

- Developing a new flood forecasting and warning system will take months to fully implement

#### Governance

- Government assistance may be required to develop and operate a flood forecasting and warning system

#### Acceptability

- High acceptability by community and government when the system regularly produces sufficiently accurate predictions

#### Feasibility and Technical Requirement

- Specialist involvement will be required to design, construct, maintain and operate the flood forecasting and warning system. The accuracy of flood predictions is influenced by the density of the hydro-meteorological network. More suited to large watersheds where sufficient lead time can be provided for communities to respond
### TABLE A.20: FLOOD EDUCATION AND READINESS

#### Overview

Flood education is a key step towards modifying a community’s response to a flood event. Sustaining an appropriate level of flood readiness is not an easy task and often involves ongoing effort by government. The community and individuals must have a good understanding of what is expected of them. A good example of the need for such understanding is evacuation. Information that defines evacuation routes, identifies emergency shelters, and specifies actions to be taken before leaving, and upon return, must be available in advance.

Ongoing flood education will improve flood readiness, and when coupled with a reliable flood forecasting and warning system provides an effective means of reducing flood damages and loss of life. Flood readiness greatly influences the time taken by flood affected people to respond effectively to flood warnings. Flood readiness includes the ability to control and minimize potential flood damages by appropriate preparatory and evacuation measures (DIPNR, 2005). Flood education and readiness is relevant for all types of flood events.

#### Advantages

- Flood education can improve community response to extreme flood events reducing flood damages and loss of life
- Enhanced flood readiness can improve the effectiveness of flood prediction and warning systems
- Extensive CAPEX is not required to construct large-scale flood protection measures

#### Disadvantages

- Ongoing OPEX is required to sustain an appropriate level of flood education and readiness
- Difficult to provide adequate flood education to all affected people due to remoteness of communities, literacy levels and availability of resources

#### Indicative Costs

- Ongoing OPEX is required to sustain an appropriate level of flood readiness of communities

#### Timing for Implementation

- Flood education is a continuous flood mitigation measure to improve flood readiness of communities and minimize flood damages and loss of life during flood events

#### Governance

- Ongoing government involvement will be required to facilitate and fund flood education of communities

#### Acceptability

- Highly acceptable to communities and governments in areas subject to regular moderate to large flood events; however, may be poorly implemented due to lack of ongoing resources and OPEX

#### Feasibility and Technical Requirement

- Flood education to improve flood readiness is an easy flood protection measure to implement; however, this may be impacted by local literacy levels, OPEX funding, resources to undertake training and access to remote communities
TABLE A.21: DEVELOPMENT OF A CLIMATE INFORMED WATER POLICY AND MANAGEMENT FRAMEWORK

**Overview**

Adaptation to climate change in the water sector needs to be incorporated into overall policy frameworks. A recent Organisation for Economic Co-operation and Development (OECD) analysis of policy frameworks for water has shown that what should be done, when and by whom depends on the rate of climate change, but also on the existing policy frameworks in each country (Levina and Adams, 2006). These policy frameworks generally contain the following elements:

- Legal Framework: a system of legal frameworks that stipulate rights and responsibilities (e.g., water rights and abstraction permits);
- Institutional Strengthening: build operation and management capability for related institutions of national, regional and local levels;
- Policies: Produce policies that guide national, regional, state, local laws;
- Clarification and Division of Roles: clearly define role for players (Governments, Ministries, departments, regulators and other authorities);
- Development of Infrastructure: Build physical water infrastructure such as dams, levees reservoirs and sewerage systems;
- Plans of Actions: Develop a set of water management plans with the flexibility to anticipate and respond to climate change; and
- Effective Uses and Sharing of Information: Establish a good practice and system for sharing current and projected climate information.

Interactions at different scales of governance are recognized as critical. Multi-level governance operates vertically across multiple levels of government (commune, provincial to national) and horizontally across government departments as well as non-government actors. Successful adaptation requires interactions between different levels of government since adaptation at one level can strengthen or weaken adaptive capacity and action at other levels; local institutions can block or support higher-level organizations.

Furthermore, it should be noted that river catchments are probably the best spatial scale to be considered for an effective implementation of raw water resources management plans. This can prove difficult for transnational rivers.

<table>
<thead>
<tr>
<th><strong>Advantages</strong></th>
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<tbody>
<tr>
<td>• Low CAPEX</td>
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<tr>
<td>• Many existing templates to model policy and framework upon</td>
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<tr>
<td>• Structure for future projects and long term planning</td>
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<table>
<thead>
<tr>
<th><strong>Disadvantages</strong></th>
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<tbody>
<tr>
<td>• Requires broad government coordination across sectors and levels</td>
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<tr>
<td>• Technical knowledge and expertise required</td>
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<tr>
<td>• Does not address immediate water concerns</td>
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<tr>
<th><strong>Indicative Costs</strong></th>
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<tbody>
<tr>
<td>• Varies depending on policy applied</td>
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<tr>
<th><strong>Timing for Implementation</strong></th>
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<tr>
<td>• 12 - 18 months</td>
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<tr>
<th><strong>Governance</strong></th>
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<tbody>
<tr>
<td>• Commune, provincial and national government coordination and input</td>
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<td>• Dialogue with international governing bodies to ensure criteria and standards are addressed</td>
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<thead>
<tr>
<th><strong>Acceptability</strong></th>
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<tbody>
<tr>
<td>• High acceptability where government communication is good</td>
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<tr>
<td>• Does not require tangible outcomes or impacts upon communities</td>
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<tr>
<th><strong>Feasibility and Technical Requirement</strong></th>
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<tbody>
<tr>
<td>• Access to the requisite knowledge, expertise and technical skills</td>
<td></td>
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<tr>
<td>• Guidance from experienced climate policy writers</td>
<td></td>
</tr>
<tr>
<td>• Training of local government staff for policy and framework requirements</td>
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**TABLE A.22: DEVELOPMENT OF WATER SENSITIVE URBAN DESIGN (WSUD) GUIDELINES**

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<tr>
<th>Overview</th>
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<tr>
<td>WSUD guidelines typically address issues around water supply and demand management with a strong focus on green infrastructure, while also considering the risks associated with non-potable water sources. The guidelines would include sections to guide practitioners on green infrastructure benefits, alternative water sources, risk management, site analysis, water balance assessment and end use treatment required. More detailed information would be developed for specific green infrastructure elements such as rainwater tanks, stormwater biofiltration and constructed wetlands. The guidelines would not provide detailed technical information but, rather, a general description of the key WSUD fundamentals. The guidelines would be a relatively short document with a strong emphasis on graphic display of the information and easy to understand principles. The guidelines would represent the cheapest and easiest to implement options from a WSUD perspective. The benefits from an improved water management perspective would be more limited than the development of WSUD strategy.</td>
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<th>Advantages</th>
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| • Enhances the current level of understanding of WSUD  
• Provides a framework for consistent implementation and integration of WSUD in new developments  
• Provides design guidance on WSUD details  
• Identifies issues that should be considered when evaluating strategies to achieve WSUD  
• Supplements (but not replaces) existing WSUD regulations and detailed design and implementation guidelines  
• Directs readers to more detailed technical WSUD literature on specific issues and for location specific advice |

<table>
<thead>
<tr>
<th>Disadvantages</th>
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</table>
| • WSUD guidelines would be more limited than a WSUD strategy due to their general nature  
• Does not take site specific conditions into account, including topography, soils, landscape, services and other relevant site features and structural elements  
• Not a stand-alone design resource |

<table>
<thead>
<tr>
<th>Indicative Costs</th>
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<tbody>
<tr>
<td>• The cost of developing WSUD guidelines would be minimal as it would not involve any specific investigations or site-specific details</td>
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<tr>
<th>Timing for Implementation</th>
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<tbody>
<tr>
<td>• The development of WSUD guidelines can be achieved in weeks to months</td>
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<th>Governance</th>
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| • WSUD is mandatory for certain scales and types of developments  
• WSUD would require involvement from relevant water utilities and their engineering divisions (or external procurement)  
• Stakeholder consultation is key |

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<th>Acceptability</th>
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| • High acceptability – usually WSUD does not result in significant disturbance to local communities  
• Little public opposition against, and considerable support for, the use of WSUD  
• Some aversion to new technology |

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<tr>
<th>Feasibility and Technical Requirement</th>
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| • Some WSUD technologies are simple to install and operate. Local people can be easily trained and construction materials are usually readily available  
• Primarily requires common engineering practices; however, some specific engineering inputs are required for design and construction as well as for specific materials that may not be local  
• Existing local skills associated with current facilities can be used for operational purposes  
• May require advanced plumbing work |
**TABLE A.23: DEVELOPMENT OF A WSUD STRATEGY AND IMPLEMENTATION OF WSUD OPTIONS**

### Overview
A detailed site analysis and water balance assessment would be the first step of a WSUD strategy. The following site characteristics should be considered as part of a detailed site analysis:

- Climate (rainfall - annual average, seasonal variation);
- Topography (steep slopes, vicinity to natural waterways);
- Soils and geology (suitability for infiltration);
- Groundwater (depth to water table);
- Salinity (acid sulphate soils);
- Space (potential areas for water treatment and storage);
- Services (conflicts with existing and proposed);
- Environmental (significant species); and
- Heritage (retrofitting plumbing on heritage listed buildings).

Secondly, an assessment of the end use and treatment required should include at least a general water breakdown in terms of internal water use (e.g., drinking, showers, toilets and laundry), external water use (e.g., irrigation, industrial plant, cooling towers), and an assessment of the suitability of alternative water sources (rainwater, stormwater, groundwater and recycled water). Finally, the strategy should determine the right balance of green infrastructure to be implemented to ensure the long term efficiency of the WSUD measures.

### Advantages
- A WSUD strategy allows for the integration of all WSUD elements within the development
- A WSUD strategy would be site and development specific as each site has specific environmental conditions that influence implementation of WSUD, such as rainfall, topography, soils, creeks and receiving waters

### Disadvantages
- WSUD upgrade requirements will vary between households and developments, increasing project complexity
- WSUD will only have an effect with widespread uptake

### Indicative Costs
- The cost of developing a WSUD strategy and implementation of WSUD options would vary on a site by site basis

### Timing for Implementation
- The development of a WSUD strategy and implementation of WSUD options can be achieved in months to years, depending on site specific details and requirements

### Governance
- WSUD is mandatory for certain scales and types of developments
- WSUD would require involvement from relevant water utilities and their engineering divisions (or external procurement if they don’t have internal capacity), participation of the general community is not required
- Stakeholder consultation is key

### Acceptability
- High acceptability – usually WSUD does not result in significant disturbance to local communities
- Little public opposition against, and considerable support for, the use of WSUD
- Some aversion to new technology

### Feasibility and Technical Requirement
- Some WSUD technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are usually readily available
- Primarily requires common engineering practices however, some specific engineering inputs are required for design and construction as well as relevant materials that may not be local
- Existing local skills can be used for operational purposes
- May require advanced plumbing work


