Approach, Methodology, and Data for Climate and Disaster Risk Screening Tool for Roads Projects

Introduction

The Climate and Disaster Risk Screening Tool for Roads Projects is designed to help World Bank staff and other development practitioners screen roads projects for risks from climate variability and change, as well as geophysical disasters. This document outlines the methodology used, including both the scientific basis and the data sources that underlie the tool's design.[1]

Purpose: The purpose of this tool is to conduct an ***early-stage screening*** as part of due diligence so that climate and disaster risks are identified and considered during the concept stage of operations. The tool is intended to help users determine the appropriate level of effort for further studies, consultation, or dialogue in the course of project design. It does not provide a detailed risk analysis, nor does it suggest specific options for increasing the project's resilience.

Relevance: This tool guides project teams through a series of screening steps. When completed, these steps connect information on relevant climate and geophysical hazard risks with the team's understanding of both their project's sensitivity and the broader development context of the project location. The risks of concern are highly dependent on project context and location. Rather than relying

Key Terminology

Adaptive capacity: "The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" of hazards.[1]

Climate hazard: Hydro-meteorological and oceanographic variables and phenomena with the potential to cause harm to human health, livelihoods, or systems, or natural resources.

Geophysical hazard: Natural land processes and events with the potential to cause harm to human health, livelihoods, or systems, or natural resources.

Exposure: "The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected" by a hazard.*

Sensitivity: "The degree to which a system or species is affected, either adversely or beneficially, by climate variability or change" or geophysical hazards.*

Potential impact: The effects on human or natural assets and systems as a result of exposure and sensitivity, either beneficial or harmful.

Risk: "The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain." This tool defines risk as a combination of exposure, sensitivity, and adaptive capacity. It does not define risk as the product of probability of hazardous events and the consequences of those events, as is frequently used.

[1] Definitions adapted from IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/report/ar5/wg2/

[2] N. Brooks, 2003. "Vulnerability, Risk and Adaptation: A Conceptual Framework" Working Paper No. 38. Tyndall Centre. http://www.tyndall.ac.uk/sites/default/files/wp38.pdf

[1] A similar methodology is applied to other tools.

on automated processes, the tool enables users to apply their subject-matter expertise and background understanding in assessing climate and disaster risks at the local level.

Screening Stages

As illustrated in **Error! Reference source not found.**, this tool applies an exposure-sensitivity-adaptive capacity framework to assess project risks. It embodies the elements of the IPCC risk analysis[2] framework and USAID's framework[3] for vulnerability assessment, with some modifications, to improve the tools usability and tailor it to (World Bank) investment projects. The IPCC (2014) defines risk as "the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values." (Risk is sometimes equated to the product of probability and impact, but in this tool, probability is not explicitly considered.)

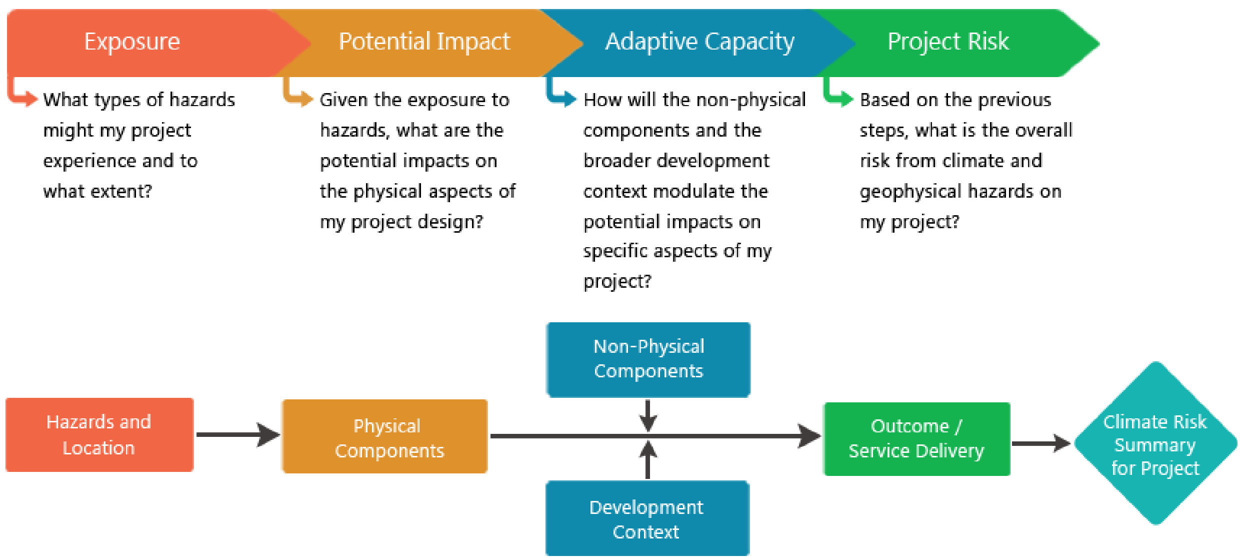

Figure 1. Tool approach: The four stages followed in the tool and their connection to the exposure-sensitivity-adaptive capacity framework.

Project Exposure

The project location's exposure to climate and geophysical hazards is evaluated in the Hazards and Location step. Exposure is the overlap between the presence of potentially damaging hazards and the location of communities, assets, and resources that are relevant to the project.

Users evaluate exposure to two sets of hazards: climate hazards and geophysical hazards.[4] The Roads tool specifically addresses the following climate hazards:

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[2] This framework is derived from the IPCC (2014) with slight modifications to improve the usability of the tool and to tailor the tool to World Bank projects.
[3] USAID, *Climate-Resilient Development: A Framework for Understanding and Addressing Climate Change* (Washington, DC: 2014).
[4] See Box 1 for definitions of key terms.

- Extreme Temperature
- Extreme Precipitation & Flooding
- Sea Level Rise
- Storm Surge
- Strong Winds

The geophysical hazards addressed in the tool are:

- Earthquakes
- Tsunamis
- Volcanic Eruptions
- Landslides[5]

The phrase "climate and geophysical hazards" captures all of the hydro-meteorological, oceanographic, and geophysical hazards listed above. These hazards were selected because they are highly relevant to roads projects. The list is not exhaustive; in some cases, certain hazards might not be explicitly addressed by the tool (examples include heat waves, drought, and freeze-thaw cycles). Users have the option of adding additional hazards to the screening list. The screening tool does not address manmade disasters, such as armed conflict or chemical spills.

Data sources: For data on hazards in the project location, the tool relies largely on the World Bank's Climate Change Knowledge Portal (CCKP) and the CCKP's Country Adaptation and Risk Profiles. The CCKP draws on global, quality-controlled datasets and is continually updated as new data become available. In some cases, the CCKP is supplemented with other sources of information. For more detail on the data used in this step, please refer to the Data Annex.

Climate time-frames: Exposure to climate hazards is evaluated in two time-frames, *Historical/Current* and *Future,* because past records are not necessarily indicative of future conditions. The *Historical/Current* time-frame is based on past extreme events and recent climate trends, such as increases in average temperature from the 1960-1990 time period to the 1990-current time period. The *Future* time-frame focuses on the climate and climate-related conditions projected under different socioeconomic scenarios.

Uncertainty and Spatial Scale of Climate Projections

The projections of future climate listed in the CCKP are currently derived from General Circulation Models (GCMs), the most advanced tools available for simulating the response of the global climate system to increasing greenhouse gas concentrations.* Caution must be used when applying these projections to project-level climate risk assessments because of the uncertainty associated with climate models. While this tool employs projections to provide a general sense of future trends, the information is not intended to be a definitive representation of the future. Further, the coarse resolution of the projections (~200 km x 200 km) does not capture climate variability within each grid cell, making the projections more difficult to apply to the spatial scale of projects. For more information on climate projections, please refer to the Data Annex.

* See Intergovernmental Panel on Climate Change, "What is a GCM?" (http://www.ipcc-data.org/guidelines/pages/gcm_guide.html)

The default future time-frame selected in the Country Adaptation and Risk profiles is mid-century: 2040-2059. This period was selected because it is most relevant to the lifetime of the World Bank's projects and investments. However, since project lifetimes vary from project to project, users should adjust the time-frame of the climate information as necessary. Figure 2 below illustrates the concept of the time scale of climate change and project lifetimes as it applies to a range of investments.

[5] Numerous factors contribute to landslides, such as earthquakes, heavy rainfall, and erosion. However, because landslides are fundamentally ground movements, rather than climatic events, they are classified here as a geophysical hazard.

Because geophysical hazards (earthquakes, tsunamis, landslides, and volcano eruptions) do not have associated future projections, exposure for those hazards is assessed only in the Historical/Current time-frame.

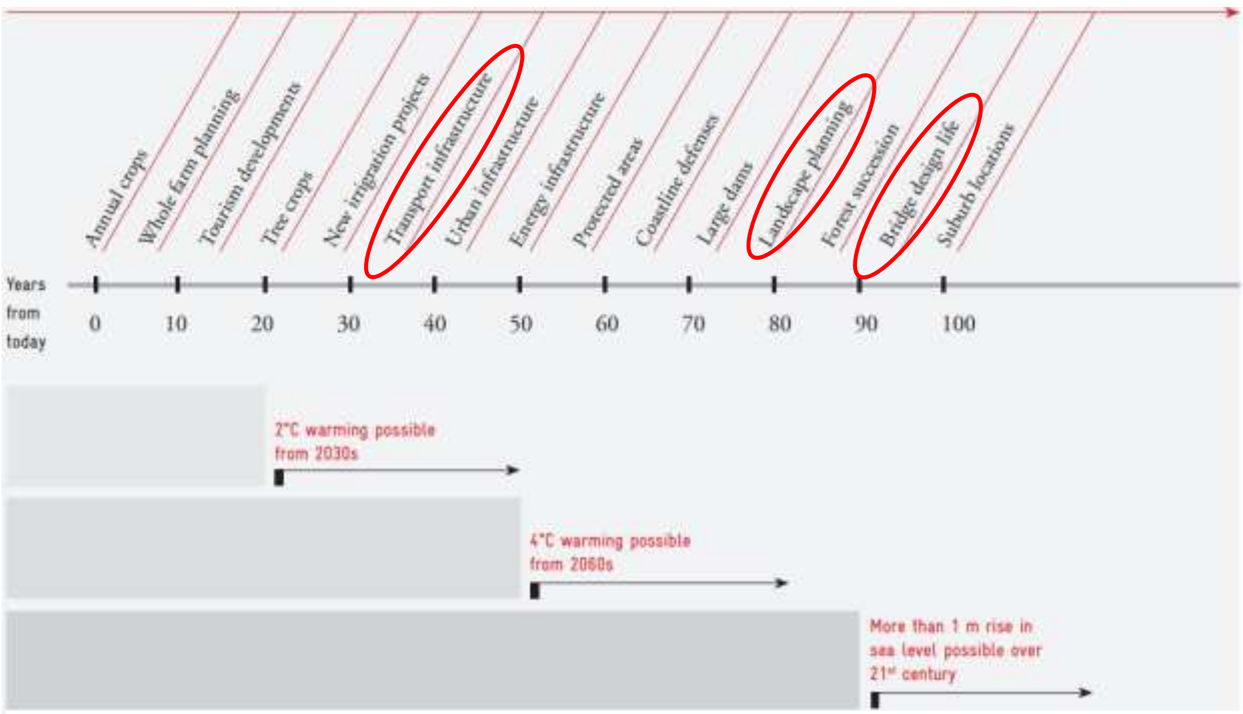

Figure 2. Time scales relevant to different types of investments.

Rating scale: The rating scale for exposure enables users to differentiate between hazards that occur with high frequency or severity, at one extreme, and those that may not be applicable to their project location, at the other. For example, inland roads may be highly exposed to extreme rainfall events, but not exposed to sea level rise or storm surge. The rating scale looks like this:

Insufficient understanding	Not Exposed	Slightly Exposed	Moderately Exposed	Highly Exposed

Potential Impact

The *potential impact* from climate and geophysical hazards on the physical and structural components of the project is assessed for each hazard. This potential impact is the combination of *exposure* and *sensitivity* of physical assets, resources, and systems. The potential impact ratings rely on the user's subject matter expertise and contextual understanding.

Evaluating historical trends: Users evaluate potential impacts separately for the *Historical/Current* and *Future* time-frames, because the level of potential impact may change as exposure changes over time. It is important to first evaluate historical trends and current baselines to understand the conditions and trends facing road systems today. For example, there may have been recent flood events that significantly exceeded the capacity of road drainage systems, causing widespread disruptions to traffic flow.

Rating future impact: Using the projections for future climate in that location and relating them to the relevant time scale (see Figure 2), users can focus on the aspects of their project that will be relevant to the outcome of the project in the *Future* time-frame. Most road investments have long lifetimes, so considering future conditions is critical to avoid “locking in” designs that are not suited for higher sea levels or more frequent flooding. Coastal roads whose design is based on current sea levels, for example, may experience periodic or permanent inundation in several decades because the elevation is insufficient.

The potential impact assessment is rated against each hazard because the nature of sensitivity and impacts varies significantly among hazards. High temperatures may lead to pavement cracking, so the temperature rating of the pavement binder is an important indicator of sensitivity to temperature. On the other hand, sensitivity to heavy rainfall and flooding depends on the capacity of road drainage, including culverts, storm drains, and ditches, as well as road surface concerns. To capture these different sensitivities (and thus potential impacts), each hazard is rated separately.

The rating scale for potential impact looks like this:

Insufficient understanding	No Potential Impact	Low Potential Impact	Moderate Potential Impact	High Potential Impact

In selecting these ratings, users overlay sensitivity considerations with the previous exposure ratings to assess potential impact. Therefore, the potential impact ratings may or may not align with the exposure ratings. For example, a rural feeder road may only be occasionally exposed to heavy rainfall events. However, if it is unpaved, then the potential impact could be very severe due to high sensitivity. The Resource Annex provides a list of resources on the potential impacts of climate change on roads.

Adaptive Capacity

At this point, users assess their project’s capacity to adapt to the risks identified in their preceding assessments. Adaptive capacity is evaluated in two steps:

- Non-physical project components
- Influence of development context

Non-physical project components: In this step, users examine those activities in their project that do not involve physical or structural work to assess how they influence the project’s adaptive capacity. This step is crucial because projects typically include a non-physical investment, such as capacity building or policy development. Such investments may have a significant influence on stakeholders’ ability to cope with the impacts of climate and geophysical hazards. This step highlights the importance of such investments in determining how impacts from climate and geophysical hazards could potentially be managed.

Influence of development context: In this step, the adaptive capacity of the broader context (the human environment outside the realm of the project) is considered. This step allows users to acknowledge social, economic, and political factors that are outside of their control but may either worsen or reduce the potentially harmful impacts of climate and geophysical hazards on their project.

Both types of adaptive capacity ratings are assessed independently of time-frame. This is because these non-physical elements do not typically have clear “lock-in” effects, unless they involve major institutional investments/changes, in the way that physical infrastructure does. The fluidity of the investments underlying non-physical components would make it too complex to determine which elements (for example, policies) would be more influential in the near-term or long-term.

In addition, adaptive capacity can change over short time periods; for example, conflict or economic recessions can rapidly reduce adaptive capacity, while early warning systems and other emergency response protocols can quickly boost adaptive capacity. Therefore, the ratings for adaptive capacity are not assigned to a specific time-frame.

Rating adaptive capacity: The non-physical components and development context ratings are not separated into hazard-specific ratings, because the influence of adaptive capacity typically applies to the impacts of all hazards. For example, well-developed transportation networks--such as those with multiple pathways between origins and destinations--can help maintain connectivity when road service is disrupted, whether the disruption stems from heavy rainfall, strong winds, or other hazards. Similarly, enhancing road maintenance can limit the damage to assets from all hazards.

The rating scale for adaptive capacity looks like this:

Insufficient understanding	Significantly Reduces Impact	Slightly Reduces Impact	Slightly Increases Impact	Significantly Increases Impact

Rather than measuring a level of potential impact, this scale reflects the *modulating effect* of adaptive capacity on potential impacts**.** It ranges from positive effects on potential impacts ("Significantly Reduces Impacts") to negative effects on potential impacts ("Significantly Increases Impacts").

Overall Project Risk

In this step, users integrate their assessments of potential impact and adaptive capacity to arrive at a rating for overall project risk.

This step is organized by hazard to reflect the different levels of potential impact that each hazard may cause.

The risk ratings are done separately for *Historical/Current* and *Future* time-frames to account for possible changes in potential impact over time.

The rating scale for project risk looks like this:

Insufficient understanding	No Risk	Low Risk	Moderate Risk	High Risk

The tool automatically summarizes the results of each step and the overall results in tables and presents them as a final report (in PDF) for the user.

Reminder: The final results of the screening, presented in the summary report, are designed to flag potential impacts and risks to projects from climate and geophysical hazards. These risk assessments may need closer attention during project preparation through further studies, consultation, and dialogue. **The screening results are not sufficient to serve as the basis for decisions regarding detailed project design.**

Data Annex

Climate Data

The Roads screening tool is linked online to the World Bank's Climate Change Knowledge Portal (CCKP) and the CCKP's Country Adaptation and Risk Profiles, allowing users to access most of the data concerning hazards in the project location. Further information on the underlying information sources can be found in the CCKP metadata description.

Main data sources: The CCKP's current datasets are based on the Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report. Future climate information in the CCKP and profiles is derived from 14 of the 23 available general circulation models (GCMs), which are physically based models of projected climate change. To understand the potential range of climate model outcomes and account for climate model uncertainties, the CCKP presents an envelope of all models depicting the ensemble median, the ensemble high (10^{th} percentile), and the ensemble low (90^{th} percentile) of the model distribution.

Emissions scenarios: Consistent with the Fourth Assessment Report, the CCKP currently uses projections from the Special Report on Emissions Scenarios (SRES) projections, which contain these two emissions scenarios (among others): SRES A2 and SRES B1. By default, the Country Adaptation Profiles display data from the SRES A2 emissions scenario, which is the higher emissions scenario and more closely associated with current estimated CO_2 concentrations in the atmosphere.[6] Climate data from the latest IPCC Fifth Assessment Report (AR5) is forthcoming (see below).

Time-frames: The default future time-frame depicted in the Country Adaptation Profiles is 2040-59, but data are available for 20-year averages through 2100. The mid-century time-frame is the default option because it is most relevant to the lifetime of World Bank's projects and investments. However, since project lifetimes can vary, users are encouraged to adjust the time-frame of the climate information as necessary to match the lifetime of project investments.

Updated data: Work is ongoing to update the CCKP with datasets from the IPCC's Fifth Assessment Report (AR5) by the end of 2015. Once updated, the CCKP and the Adaptation Profiles will include the CMIP5 climate models from the AR5 for all four Representative Concentration Pathways (RCPs) (2.6; 4.5; 6.0; 8.5) and four time periods (2020, 2050, 2070, and 2090).[7] The CCKP will include all model output means as well as the anomaly of the models in comparison with historical data. Model uncertainty is depicted through the 90th and 10th percentile distribution of ensemble models.

Spatial scales: The spatial resolution currently provided in the CCKP and the Country Adaptation and Risk Profiles varies among datasets. The historical dataset in the CCKP is represented with a global dataset available at a native scale of 50 km x 50 km (produced by the Climatic Research Unit (CRU), University of East Anglia). Future projections are displayed in their native GCMs resolutions at a 2° scale

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[6] Additional information on these emissions scenarios can be found in an IPCC report, available online here: http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0

[7] Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its Fifth Assessment Report (AR5). The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively).

(~200 km x 200 km). The coarse resolution might not allow for a detailed assessment of climate variability within each grid cell.

The Climate Analysis Tool of the CCKP provides a visualization of global downscaled climate models with daily data at a 0.5° scale (~50 km x 50 km). Users can access this by clicking the *Future Climate>Downscaled Climate* tab within the CCKP country pages. It is important to keep in mind that uncertainty increases the further these global datasets are downscaled and its outcomes should be interpreted with caution.

The *Risk Screening Overview* tab of the Country Adaptation and Risk profile to which the screening tools are currently hyperlinked provide the following resolutions: 50km x 50km for historical information; and ~200 km x 200 km for future climate projections. The tool utilizes the A2 default scenario to help users understand and plan for scenarios of greater climate change and the associated risk to World Bank projects.

The sections below address those datasets that are not currently in the CCKP,[8] highlighting exposure-related thresholds used in Stage 1 ("Screen for exposure to climate and disaster risks") for sea level rise, storm surge, and strong winds used in the screening tool.

Sea Level Rise

Sea level is a function of numerous climatic and non-climatic factors, including ocean thermal expansion, melting from glaciers and ice sheets, land uplift, and groundwater depletion, among others. There is significant uncertainty regarding the extent of future sea level rise in particular locations and for particular decades.

Range of projections: The IPCC's *Fifth Assessment Report* provides scenarios of global mean sea level rise that are below 1 meter by 2100; however, there is significant evidence for greater increases in sea level in the literature.[9] The IPCC's assessment relies on process-based projections and does not incorporate semi-empirical projections because of low confidence levels in the results. However, these semi-empirical models project greater rises in sea level, with an upper bound sometimes exceeding 1.5 meters by 2100.[10] The U.S. National Climate Assessment projects rising of up to 2 meters in global mean sea level over this period, and the IPCC cites reports with estimates of up to 2.4 meters.[11]

Given the range of these sea level rise projections, *project teams using this tool should apply the upper end of the estimates to provide a conservative screen for project managers*.

Calculation of accelerating rise: A default Future time-frame in the screening tool is 2040-2059, since many project lifetimes will not reach the end of the century. Sea level rise is not projected as a constant increase over time; rather, the rate accelerates from the current ~3 mm/year to up to roughly 15 mm/year by the end of the century.[12]

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[8] Please note the CCKP will be constantly updated to include more datasets as resources are made available.

[9] See Figure 13.11a in in J.A. Church et al., eds., "Sea Level Change," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T. F. Stocker et al. (Cambridge and New York: Cambridge University Press).

[10] See Figure 13.12d in Church et al., "Sea Level Change."

[11] U.S. Global Change Research Program, 2014 National Climate Assessment (Washington: 2014) (http://nca2014.globalchange.gov/report)

[12] See Figure 13.11b in Church et al., "Sea Level Change."

Note: To estimate an upper end of global mean sea level rise in the middle of the century, a quadratic relationship is used to calculate change from 1992 (the starting point) to 2050: $E(t) = 0.0017t + bt^2$*, where E is global mean sea level rise in meters, t is the number of years since 1992, and b is a constant that ranges from 0 (lowest scenario) to* $1.56x10^{-4}$ *(highest scenario).[13] This equation yields an upper-end estimate of a rise of 0.62 meters in sea level by 2050, which is rounded to 0.6 meters for the sake of the tool.*

Local vs. global rates: Caution should be used with such thresholds because local sea level change can vary significantly from global averages. For example, local sea level can be strongly influenced by local factors such as uplift or subsidence of the land surface, erosion (i.e., sediment removal), and accretion (i.e., sediment addition) in the project area. Rates of current local sea level rise data can be viewed in a "Tides and Currents" web page from the U.S. National Oceanic and Atmospheric Administration (NOAA). It is likely that these rates will increase in the future. They therefore generally represent a minimum rate of rise (or a maximum level of decrease in areas of rapid subsidence).

Upper bounds: An appropriate upper bound for a rate of sea level rise depends on the project lifetime. For projects with short lifetimes of 10-20 years, the rate of sea level change will resemble the Historical/Current rate. However, as mentioned above, the rate of global mean sea level rise is projected to increase over time. For projects with lifetimes that stretch beyond mid-century, a maximum sea level rise rate of 15 mm/year can be applied over the project's service life.[14] Again, this is a conservative screen focused on the upper bound of projections.

As an example, if a project has an expected service life of 70 years, the maximum sea level rise that could be expected is roughly 1.05 meters x (0.015m/yr * 70 yrs).

If the contributions of local drivers of sea level change are known (e.g., through consultation with local experts), the following formula can be used to estimate future sea level rise:

$$Local\ rate\ of\ sea\ level\ change = Global\ mean\ sea\ level\ rise + Local\ drivers\ of\ sea\ level\ change$$

Storm Surge

Historical/Current: To assess the project location's exposure to storm surge in the Historical/Current time-frame, a conservative screen of 10 meters is applied. That is, if the project elevation is 10 meters above the present maximum high tide level, then the project will not likely be exposed to storm surge.

The 10 meter elevation threshold indicated above is roughly the elevation of the greatest historical storm surge and wave run-up heights.

The highest storm surge in the past century occurred during the Great Bhola Cyclone of 1970 in the Bay of Bengal, when a storm surge of 10.6 meters occurred during one of the highest high tides of the year.[15]

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[13] National Oceanic and Atmospheric Administration, *Global Sea Level Rise Scenarios for the United States, National Climate Assessment,* NOAA Technical Report OAR CPO-1, (Washington: 2012) (http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf)

[14] See Table 13.5 in Church et al., "Sea Level Change."

[15] M.K. Karim, and N. Mimura, "Impacts of Climate Change and Sea-level Rise on Cyclonic Storm Surge Floods in Bangladesh," *Global Environmental Change*, vol. 18, no. 3: 490-500 (2008) (doi:10.1016/j.gloenvcha.2008.05.002); and M.L. Shrestha, ed., *The Impact of Tropical Cyclones on the Coastal Regions of SAARC Countries and Their Influence in the Region* (Bangladesh: SMRC N. SAARC Meteorological Research Centre, DHA, October 1998).

The highest storm surge on record in the United States was from Hurricane Katrina in 2005, measured at 8.4 meters above the normal astronomical tide level.[16]

There are far more sophisticated techniques for estimating maximum storm surge involving numerical modeling. However, the threshold approach in this tool is adequate for the coarse, rapid screening purposes of this tool. (However, it is important to note that increases in sea level are not equivalent to increases in storm surge height.)

Future: To assess whether the project will be exposed to future storm surge, the tool helps the user to identify whether the project elevation is within 11 meters' elevation of the present maximum high tide level. Storm surge height is likely to be increased by sea level rise. The 11 meter threshold is based on a combination of the maximum present day surge values (10 meters) and the upper end of sea level rise projections for 2050 (0.6 meters). (See "Storm Surge: Historical/Current" section above and "Sea Level Rise" section on preceding page.)

Both thresholds suggested under this (storm surge) hazard are intended to be conservative screens to determine whether the project location could experience storm surge. They do not reflect whether the project location is likely to experience tropical cyclones or the distance inland that a storm surge may travel. (For assessments of exposure to cyclones and other wind hazards, see "Strong Winds" section, next page.)

More precise estimates of changes in the magnitude of future storm surge are difficult to make and are relatively uncertain. There is high confidence that storm surge extremes will increase with sea level rise, yet there is low confidence in region-specific projections in storminess and storm surges.[17] As noted above, numerical modeling techniques can be used to simulate storm surge if more precise information on storm surge is needed to refine the estimates of risk to the project.

Strong Winds

Historical/Current: Strong winds are related to tropical cyclone, thunderstorms, tornadoes, frontal winds, downslope winds, and dust storms and other desert winds. Through the Country Adaptation and Risk Profiles in the CCKP, the cyclone hazard mapping tool can be used to identify project locations that are exposed to strong winds from tropical cyclones. However, high quality local information about damaging winds that are not due to tropical cyclones is difficult to obtain. This information may be available from other sources, such as the project country's National Meteorological Service (see www.wmo.int/pages/members/members_en.html for a country listing).

Future: Average tropical cyclone maximum wind speed is likely to increase over the 21st century, although increases may not occur in all ocean basins.[18] The details of these changes are highly uncertain. The *frequency* of future tropical cyclones is even more uncertain. It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged.[19] The most authoritative source of information on future regional and global changes in extreme events currently is the IPCC *Special*

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[16] R.D. Knabb, J.R. Rhome, and D.P. Brown, "Tropical Cyclone Report, Hurricane Katrina, 23-30 August 2005" (Washington: National Oceanic and Atmospheric Administration, 2005). (http://www.nhc.noaa.gov/pdf/TCR-AL122005_Katrina.pdf)

[17] Church et al., "Sea Level Change."

[18] J.H. Christensen et al., "Climate Phenomena and their Relevance for Future Regional Climate Change," in *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T.F. Stocker (Cambridge and New York: Cambridge University Press, 2013).

[19] Christensen et al., "Climate Phenomena and their Relevance for Future Regional Climate Change."

Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)[20].

Geophysical Hazards

The CCKP also provides a general view of global hydro-meteorological and geophysical natural hazard datasets and historical disaster loss information that are available from a range of open data sources, including the Natural Disaster Hotspots from CIESIN, the Global Risk Data Platform from UNEP/UNISDR, the OFDA/CRED International Disaster Database (EM-DAT), and the National Geophysical Data Center/World Data Center (NGDC/WDC)[21].

[20] C.B. Field et al., eds., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, (Cambridge and New York: Cambridge University Press, 2012).

[21] Background information on the data in the Climate Change Knowledge Portal may be found at this CCKP web page: http://sdwebx.worldbank.org/climateportal/documents/Metadata-Portal.pdf

Resource Annex

For information on climate data:

- The World Bank's Climate Change Knowledge Portal (CCKP) provides historical and future climate and climate-related datasets.
- The CCKP's Country Adaptation and Risk Profiles synthesize and distill datasets for the purposes of the screening tool.
- The Intergovernmental Panel on Climate Change (IPCC) Working Group I's contribution to the IPCC's Fifth Assessment Report presents the latest (as of summer 2014) in observed climate changes and future climate projections.

For more information on climate change impacts on transportation systems:

- Turn Down the Heat: Why a 4°C Warmer World Must be Avoided is a World Bank report focused on the impacts of climate change on developing countries.

- Turn Down the Heat: Climate Extremes, Regional Impacts and the Case for Resilience builds on the previous report and focuses on impacts in Sub-Saharan Africa, South East Asia and South Asia.

- Turn Down the Heat: Confronting the New Climate Normal is a World Bank Report that builds on previous reports and focuses on impacts to development in Latin America and the Caribbean, the Middle East and North Africa, and parts of Europe and Central Asia.

- Potential Impacts of Climate Change on U.S. Transportation by the U.S. Transportation Research Board identifies climate vulnerabilities to the transportation system.

- "Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I". This study explores how climate will affect transportation, and Table 1.1 identifies a comprehensive list of climate impacts on transportation identified through a literature review.

- Addressing Climate Change Impacts on Infrastructure: Transportation is a factsheet released by USAID which summarizes climate stressors on transportation systems.

For more information on case studies that identify climate change impacts and vulnerabilities to a country's transportation system:

- The World Bank series *Making Transport Climate Resilient*, includes three case studies, Country Report: Ghana, Country Report: Ethiopia, and Country Report: Mozambique that identify country-specific climate impacts to roads, identify adaptation measures, conduct economic assessments, and develop short- and long- term strategies.

- Asian Development Bank's "Climate Proofing: A Risk-based Approach to Adaptation" features a case study, Climate Proofing a Road-building Infrastructure Project in Kosrae, Federated State of Micronesia. The analysis develops a climate-proofed design adjusted for rainfall projections and estimates the design's marginal cost and net benefit.

- The UK Highways Agency Climate Change Risk Assessment identifies climate risk by scoring and ranking the vulnerability of the agency's assets.

- Design Standards for U.S. Transportation Infrastructure: The Implications of Climate Change examines how climate can impact transportation design and identifies strategies to reduce risk through means other than altering design standards.

For more information on evaluating climate change vulnerability to transportation systems:

- The U.S. Federal Highway Administration's (FHWA) Climate Change & Extreme Weather Vulnerability Assessment Framework is a guide for conducting vulnerability assessments of transportation assets and systems. It uses in-practice examples to demonstrate a variety of ways to gather and process information.

- The Use of Climate Information in Vulnerability Assessments by the U.S. FHWA provides recommendations on how to use historical and projected climate information as transportation planners consider their climate-related risks.

- Assessing Criticality in Transportation Adaptation Planning by the U.S. FHWA identifies a conceptual framework for narrowing the universe of transportation assets to study in a climate change vulnerability and risk assessment.

- Assessing the Sensitivity of Transportation Assets to Climate Change in Mobile, Alabama introduces the Sensitivity Screen, for planners to identify assets that are sensitive to a particular climate impact, and the Sensitivity Matrix, which enables planners to identify a deeper level of detail, including information on the threshold at which assets become sensitive and features of the asset which may be associated with increased sensitivity.

- The World Bank's Highway Development and Management Model (HDM-4) Dissemination Tools can help to predicts road network performance as a function of climate, among other input factors.