BASIC INFRASTRUCTURE FOR INCLUSIVE GROWTH IN THE NORTH CENTRAL PROVINCES SECTOR PROJECT

CLIMATE RISK AND VULNERABILITY ASSESSMENT (CRVA)

Prepared for

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ABBREVIATIONS

ADB	–	Asian Development Bank
AMSL	–	Above mean sea level
BIIG	–	Basic Infrastructure for Inclusive Growth
CC	–	Climate Change
CCA	–	Climate change adaptation
cm	–	Centimeter
CMIP	–	Coupled Model Intercomparison Project
CRVA	–	Climate Risk and Vulnerability Assessment
CSIRO	–	Commonwealth Scientific and Industrial Research Organisation
DARD	–	Department of Agriculture and Rural Development
DED	–	Detailed engineering design
DoC	–	Department of Construction
DoNRE	–	Department of Natural Resources and Environment
DPI	–	Department of Planning and Investment
EA	–	Executing Agency
EARF	–	Environmental Assessment and Review Framework
ENSO	–	El Niño–Southern Oscillation
GCM	–	Global Climate Model
GHG	–	Greenhouse gas
GoV	–	Government of Viet Nam
IMHEN	–	Institute of Meteorology, Hydrology and Environment
IPCC	–	Inter-Governmental Panel on Climate Change
LST	–	Longshore sediment transport
MCM	–	Million cubic meters
mm	–	Millimeter
MoNRE	–	Ministry of Natural Resources and Environment
NH	–	National Highway
PPC	–	Provincial People’s Committee
PPMU	–	Provincial Project Management Unit
PPTA	–	Project Preparation Technical Assistance
PRECIS	–	Providing Regional Climates for Impacts Studies
RCM	–	Regional Climate Model
RCP	–	Representative Concentration Pathway
RUSLE	–	Revised Universal Soil Loss Equation
SLR	–	Sea Level Rise
SRES	–	IPCC Special Report on Emission Scenarios

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EXECUTIVE SUMMARY

1. The Basic Infrastructure for Inclusive Growth inNghe An, Ha Tinh, Quang Binh and Quang Tri Provinces Sector Project (BIIG2) will enhance opportunities for inclusive economic growth through improved transport and other productive rural infrastructure. The following report assesses the possible extent of climatic risk that the proposed infrastructure may face through an assessment of the representative subprojects. Representative subprojects were examined to assess climate change risks based on preliminary engineering specifications and site conditions that, together with climate change and sea level rise projections, to determine vulnerability.

2. Risk in this assessment considers the likelihood of an adverse event and its consequence—the event being the climate hazard, and the consequence depending on exposure and sensitivity of the infrastructure.

3. Climate risk is indicated by a projected increase in annual rainfall ranging from 10 to 11.5% across the 4 provinces by 2030s, and 12 to 17% by mid-century. Much of the added rain will come in the form of more intense rainfall. Based on 2 scenarios (RCP 4.5 and RCP 8.5) and using ensemble climate modeling, the annual maximum 1-day rainfall in the 4 provinces is projected to increase within a range of 21 to 43% by 2030s relative to 1986-2005. By mid-century the corresponding projected increase is 26 to 45%. For the 5-day maximum rainfall, an indicator of inundation flood risk, the projected increase is within a range of 21 to 35% by 2030s, and by 19 to 45% at mid-century.

4. Although the projected change in average temperature may look modest at 0.6°C and 1.5°C by 2030s and at mid-century, respectively, the projected change in extreme temperatures is significant. The number of consecutive days with maximum temperatures exceeding 35°C is projected to increase across all 4 provinces within a range of 28 to 67% by 2030s under the 2 RCP scenarios above. At mid-century, the corresponding projected increase is in the range of 88 to 155%.

5. Sea level rise projections, from multiple models, indicate an average of 13 cm by 2030, and 23.5cm at mid-century along the coast spanned by the 4 provinces. Between Nghe An and Ha Tinh, the highest storm surge observed to date was 400 cm. MoNRE has estimated that the highest storm surge that can occur in this coastal stretch is 450 cm. Between Quang Binh and Hue, the highest observed storm surge was 300 cm (plus 50 cm for the highest possible height, according to MoNRE).

6. The CRVA addressed (i) which climate parameters are critical to infrastructure performance and durability, (ii) how these climate parameters projected to change in future decades, (iii) if existing assets are already being affected by increasing climate variability and extremes, (iv) if non-climate factors aggravate or mitigate the impact of climate change, (v) how vulnerable is the proposed infrastructure considering these factors, (vi) what measures should be taken, including follow-up assessments during detailed design, (vii) what modification to the Environmental Assessment and Review Framework (EARF) is necessary for processing additional subprojects.

7. The *representative* subprojects include, mountain roads upgrading in Nghe An and Quang Tri, coastal road upgrading in Quang Binh and water supply in Ha Tinh province. Two *additional* subprojects (whose feasibility studies have yet to be prepared) were assessed preliminarily to cover the varied infrastructure types: (i) a river flood embankment in Nghe An and (ii) upgrading

of a fishing port in Quang Binh. Assessment of mountain roads covered vertical clearance of bridges, provisions for road drainage and slope stability, and pavement quality. For coastal infrastructure (including coastal roads, fish port and flood embankments) assessment covered elevation of structures with respect to projected SLR and sea surge heights. The assessment of the water supply risk was primarily on the dependability of the proposed source. Findings are summarized below.

8. The *Gio Linh – Cam Lo road* in Quang Tri was proposed to be upgraded to Category 5 (mountain road), but projected traffic volumes require a category 4 design, increasing the strength and design standards. The further strengthening of the road makes it more climate resilient because the engineering specifications for a Category 4 road provide for better drainage, road foundation, pavement and slope protection. Nevertheless, there remain aspects that make the subproject vulnerable to climate risk: (i) cut areas in the mid-section of the road will be more vulnerable to landslides under climate change scenarios that involve higher intensity and increased seasonality of rainfall, (ii) erodible soils along the route require care in their use as embankment fill near waterways; and (iii) bridges need to be checked for adequate vertical clearance to accommodate future flood flows under climate change.

9. Preliminary design shows some deep cuts at the central hilly section of the road. The geology of the area will be verified during detailed engineering design (DED), in view of erodible soils and exposure to projected heavier rainfall. Four existing small bridges are to be improved. For two of these bridges, the bridge deck elevation is above the 25-year flood (as required by TCVN design standards for small bridges). However, the elevation of their decks is below the level of the highest recorded flood. With projected increases in rainfall and rainfall intensity, the bridges as designed are at risk to overtopping and related debris-damage. During DED bridge levels need to be reviewed with, as a minimum requirement, the design 25-year flood defined with inclusion of projected climate change and perhaps providing additional clearance for larger flood events. This needs to be checked during the DED with reference to CC-adjusted hydro-climate data.

10. A large bridge, which is to be built across the Hieu River, has adequate vertical clearance from both the estimated 100-year flood and highest recorded flood. However, the 100-year flood level was estimated based on only 8 years of data (2009-2016). This should be verified during DED. The highest recorded flood level occurred in 2009, the same year that river gauging apparently started. It is possible that there may have been higher unrecorded flood levels prior to 2009. In view of combined climate change and land use change, the true level of the 100-year flood is likely to be higher. Fortunately, the present design clearance of 2.5 to 3.2 m gives adequate margin for risk.

11. For the *Dinh Son – Anh Son Road* in Nghe An, involves an upgrading to Category 4 (mountainous) road. The design element most at risk is the proposed clearance of the large bridge to replace an existing causeway. The bridge deck elevation is about 7 m above the existing causeway surface, corresponding to a design clearance of 1 m above the historical maximum flood which occurred in 1988. This flood is reportedly equivalent to the 100-year event, and serves as the 100-year design flood (P=1%). During DED, the magnitude and level associated with this design flood, which was based on historical records, should be verified with reference to CC-adjusted data, however initial review suggests a low risk to the current design specification.

12. Further risks include the impact of increased rainfall on road drainage. Soil type in the area is clayey which is prone to deformation when saturated and subjected to dynamic loading-leading to pavement cracks that overtime deteriorate to potholes, which then collect more water

creating a vicious cycle of accelerated degradation. Design should be based on keeping the road structure impervious to water. This is not always possible but needs to be maximized through proper drainage design. The preliminary specifications address this by adding a 25-cm aggregate sub-base layer and provisioning for lined side drains. The existing road's cross drains (culverts) are already clogged or buried and, because they are only 75 cm wide, are hard to clean. Use of larger culverts for Category 4 specifications should be a priority in the road upgrading.

13. The *Bao Ninh – Hai Ninh Coastal Road* in Quang Binh will have a road-top elevation ranging from 4.1 to 9.9 m above mean sea level. MoNRE's median projection of sea level rise in this coastal region, under a worst-case climate scenario (RCP 8.5), is 25 cm by 2050. At this raised mean sea level, the road's lowest section will be at 3.85 m elevation. During high tide (1 meter above mean sea level at P2% frequency) the high-water line at this lowest section of the road will be 2.85 m below the pavement and around 2.5 m below the level of the sub-base. The road therefore appears to have a margin of safety against effects of sea level rise.

14. The impact of extreme precipitation under climate change may have more significant future impact. The road sits on a sandy foundation because of proximity to the sea. While sand is a strong foundation material when compacted and confined, it is easily erodible when exposed to moving water. In the existing road, a short section failed apparently due to scouring of the foundation supporting a box culvert crossing, during a flood in 2016. In one of the spillway crossings, the apron below the culvert also collapsed apparently due to the weak support and anchoring provided by the sand foundation.

15. Even though the streams crossed by the road are small, projected increased rainfall intensity combined with the inherently loose/sandy characteristic of the road foundation make culvert placements vulnerable to scour and collapse. These are already addressed in the preliminary engineering design minimizing the risk.

16. For the *Rural Water Supply Scheme* in Ha Tinh province, water for the southern network is to be taken from a recently installed main line that connects to the city's water supply. The current supply for this network is not considered vulnerable, with the subproject mainly extending the existing distribution system and providing auxiliary facilities.

17. The larger northern network will source water from the existing Cu Lay reservoir used for irrigation. In terms of climate vulnerability, use of a reservoir enhances resilience of water supply by balancing water availability over the year. This is important given the natural high variability and extremes of rainfall and streamflow in the area. Such variability is likely to become more pronounced with climate change, even as total annual rainfall is projected to increase.

18. The reservoir water diverted from irrigators will be replaced through increased water provision from the Nghen river using an existing water transfer canal that will be rehabilitated to increase distribution efficiency. At present, the usable annual water volume from the reservoir—available 75% of the time-is 17.6 million cubic meters (MCM), of which 15.06 MCM is used for irrigation and 2 MCM goes to evaporation loss. Since an estimated 2.55 MCM is required to supply the new drinking water supply network, a deficit of at least 2 MCM for irrigation needs to be sourced elsewhere.

19. The use of the Cu Lay reservoir as the proposed water supply scheme water source shifts the vulnerability to water shortages to the irrigators who if reliant on the reservoir face reduced water availability during the dry season. The subproject has addressed this by replacing the diverted reservoir supply and any shortages through increasing the volume of water delivered to

the command areas from the existing Nghen River canal. The river system has adequate average water flows, but it is subject to tidal effects and hence to salinity intrusion during the dry season. Tide and salinity intrusion is increased by climate change through sea level rise. In this case, however, a salinity intrusion barrier already exists, which has the effect of transferring water to the (man-made) Nghen River. As such there is no expected risk from saline intrusion or tidal surge.

20. For the additional subproject *on River Flood Embankment* in Phuc To (Nghe An), the main CC issue is the freeboard of the dyke, i.e., the difference between the design flood level and the top elevation of the dyke. According to TCVN 9902:2013, the dyke top must be set based on the P5% (20-year return period) high- water level, plus allowances for wave height in the river, subsidence and a safety margin. This works out to a value of 3.98 m according to DPI’s preliminary calculations, rounded off in the design drawings to 4 m. The calculated P5% flood is 3.3 m, so the allowance for freeboard is 0.7 m (4 minus 3.3).

21. Mean sea level rise for the subregion is 8 to 18 cm by 2030s, and 13 to 32 cm by 2050 (with 90% confidence based on the ensemble of climate models) for scenario RCP 4.5. For RCP 8.5, the projected increase in average sea level is 9 to 18 cm by 2030s and 17 to 35 cm by 2050s. Using the median of these projections, the dyke freeboard is reduced to just 57 cm in the 2030s for both RCP 4.5 and 8.5. However, this does not yet account for probably increases in sea surge height due to CC, which according to MoNRE could increase by up to 50 cm. Using this probability argument, there is room to re-assess the dyke top level as currently designed if future climate is accounted for. A significant issue is that the dyke will effectively polder the area between the proposed dyke and the existing dyke network. Any increase in the top level for the proposed dyke will exceed the existing dyke elevation and as such the effectiveness of the dyke in providing flood protection under climate change projections without commensurate upgrading of adjacent dykes needs to be established.

22. For the *Giang River Fishing Port* additional subproject in Quang Binh, the climate risk relates to flooding as determined by extreme precipitation and sea surge events through its impact on port operations (i.e., severe disruption and water damage to power generators and cooling units). Projected future increase in hot days may also affect fish quality (and addressed in the port upgrading plan, e.g., a covered fish handling area and improved fish storage).

23. The jetty’s present 2.1 m elevation is equivalent to 1.85 m by mid-century (considering the 0.25 m projected SLR under RCP 8.5). If tidal range is unchanged, the 50-yr high tide level will then be at around 0.75 m below the jetty by mid-century (compared to present 1.1 m), which represents the allowance for flooding if it coincided with high tide.

24. Vital port facilities are to be upgraded atop raised floors: 3.2 m for the power generators (i.e., 1.7 m above highest recorded water level), and 2.4 m for both the fish processing house and fish storage area (0.9 m above highest recorded water level). The power generators will be above the highest observed storm surge level in that coastal region (3 m), but still 30 cm below the highest storm surge that, according to MoNRE, can occur with climate change. The port upgrading will include a covered fish handling area and improved fish storage facilities, which will mitigate risks of future hot weather.

25. For all subprojects, recommendations are given for the DED. Specific measures to be incorporated during the DED phase for water water-sensitive infrastructure will be based on further analysis of projected changes in frequency and magnitude of key design parameters, such

maximum rainfall intensities, supported by hydrological and flood modeling. Findings will be used to recommend adjustments to the standards used for drainage design and bridge clearances.

26. For roads, the detailed design also needs to reflect the sensitivity of asphalt pavement stiffness to high temperatures, including potential problems with migration of liquid asphalt under prolonged hot weather. Heat wave duration is projected to increase. Quality of asphalt material used in road construction and maintenance is an important resilience measure. Detailed design work on the roads should consider and include developments in asphalt technology to check for modified binders that improve the performance of asphalt under increasingly hot weather.

I. INTRODUCTION

A. The Project

1. The Basic Infrastructure for Inclusive Growth in Nghe An, Ha Tinh, Quang Binh and Quang Tri Provinces Sector Project (Project) is proposed to be implemented in four of Viet Nam's north-central provinces: Ha Tinh, Nghe An, Quang Binh and Quang Tri. The project Executing Agency (EA) will be each Provincial People's Committee who have delegated their respective Departments of Investment and Planning (DPI) as project owners. Project focus is on improving network connectivity and interprovincial connectivity, and planning prioritizes these interprovincial linkages as a core strategy to accelerate growth. The project's expected outcome is service delivery in four NCPs improved through the following outputs: (i) FNCP transport infrastructure improved; (ii) productive infrastructure for business development improved (water supply and coastal protection), and (iii) decentralized public asset management processes established.

2. Using ADB's sector project approach, *representative* subprojects are used to test the feasibility of the proposed investment. There are 4 representative subprojects, one for each province being three roads for output1 and 1 water supply for output 2. The assessment of climate risk and vulnerability is focused on these representative subprojects whose main features are presented in Table 1.

Table 1. Representative Subprojects in BIIG2

Subproject	Features
Water supply for Loc Ha district and Can Loc district *Ha Tinh*	The southern Loc Ha network will be an extension of Ha Tinh city's existing water supply network and provide 2,500m^3/day to 4,587 households by 2030. The subproject will provide 2 water storage tanks, 3 pumps and a 162km distribution network. The northern Can Loc network sources water from the existing Cu Lay irrigation reservoir to supply 7,000m^3/day to 10,984 households by 2030. The reservoir, with 13 million cubic meters (MCM) capacity, is located 4.6 km from the planned service area. Water treatment facilities and a gravity-based distribution network are to be provided. Reservoir water currently used for irrigation that is to be diverted for the water supply, estimated at 2 MCM/yr, will be replaced by transferring water more efficiently from the existing Nghen River canal into the irrigation command area.
Dinh Son – Anh Son mountain road *Nghe An*	The existing 8-km asphalt road was originally planned to be upgraded to Category 5 (mountain road) is badly degraded due to traffic volume and the axle weight of trucks. The route passes through some densely populated sections, agricultural fields and flat lands. There are 3 existing bridges plus a causeway that will be replaced with a bridge. Longitudinal and cross gradients are not high, and the existing subgrade has been assessed as suitable. Surfacing will be with asphalt concrete. The PPTA recommended that upgrading to a higher standard (Category 4) was warranted by the traffic forecast, and this will be specified during detailed engineering design.
Bao Ninh – Hai Ninh coastal road *Quang Binh*	The existing coastal road is unpaved. The road is to be improved to support tourism access. Upgrading to category 5 plain road involves widening to 7.5 m, adding 2 layers of base (14 cm) and sub-base (16 cm), and surfacing with 7 cm of asphalt concrete. When finished, the 10.6 km road will have a road-top elevation ranging from 4.1 to 9.9 m above mean sea level. A new 600-m section will provide a commune bypass is to be constructed at the south end of the alignment. Two spillway-culvert crossings will be replaced. Twenty-eight new culverts will be added to the existing 15.

Gio Linh – Cam Lo mountain road *Quang Tri*	An existing earth road, it was originally planned by DoT to be upgraded to Category 5 (mountain road), but based on projected traffic the PPTA recommended that it instead be upgraded to Category 4. The road will be 23 km long. The terrain is flat to undulating, except for the 3 to 4 km mid-section which is hilly. Eight spillway crossings over shallow streams and localized depressions will be improved/replaced. Four existing bridges with lengths of up to 24 meters will be improved. A new 132-m long bridge will be built across the Hieu River.

3. Under Output 2, *additional* subprojects have also been identified that include flood protection embankments, irrigation and drainage, and port development. This report provides a preliminary assessment of risks for two additional coastal infrastructure subprojects, both located in estuaries: (i) a 1.9 km river flood embankment to protect a community in Nghe An and (ii) upgrading of a fishing port in Quang Binh.[1]

B. Purpose of the CRVA

4. Purpose is to identify and assess risks based on the preliminary engineering specifications and site conditions of representative subprojects in BIIG-2 that, together with climate change (CC) and sea level rise (SLR) projections for the four coastal provinces, determine their vulnerability to climate-based risk.

i. For the mountain roads, aspects assessed include: (i) the vertical clearance of bridges above high water for rivers and stream crossings; (ii) design provisions for the road structure, drainage and slope stability/protection on embankment sides and at road-cut sections to anticipate increased rainfall intensity, and (iii) design provisions for pavement durability to withstand temperature rise.

ii. For coastal infrastructure (notably coastal roads, but also flood protection embankments and fishing ports), aspects assessed include: (i) elevation of structures (e.g., road embankment and fish port jetty) with respect to projected SLR and its related effect on extreme high tide and typhoon-induced sea surge, and (ii) design provisions for adequate drainage and for future increased duration of hot days.

iii. For water supply infrastructure, aspects assessed mainly cover: (i) dependability of the water supply source, and (ii) measures to control erosion and reservoir siltation.

5. Risk in this assessment follows the conventional definition of likelihood of an adverse event and its consequence—the event being the climate hazard, and the consequence depending on the vulnerability of the infrastructure. The latter in turn depends on sensitivity factors (due to the nature of the infrastructure), its degree of exposure (e.g., location) and relevant non-climate factors.

6. Based on the risk and vulnerability assessment, subproject-specific climate resilience measures are identified along with recommendations for the detailed engineering and design phase. Specific measures to be incorporated in the subproject design at that stage will be based on further analysis of (modeling-derived) projected changes in frequency and magnitude of key parameters, such as one-day maximum rainfall.

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[1] Lacking complete specifications and feasibility studies at this stage of project preparation, it is not possible to conduct systematic vulnerability assessments for these additional subprojects.

7. The CRVA framework and steps follow guidelines issued by ADB for climate proofing of roads and water supply projects. For this assessment, we followed the steps below (discussed in Annex C). These steps will be incorporated in EARF which will be used to assess additional subprojects under the sector loan.

i. Review based on literature the sensitivity of major subproject types to specific climate parameters (i.e., which climate parameters are critical to performance and durability, and in what way? Are existing assets already being affected by increasing variability and extremes in these parameters under the current climate?).

ii. Using modeling-based projections, assess how the critical climate parameters are expected to change during early century (2016-35) and mid-century (2046-65), including levels of confidence based on degree of agreement among the models used.

iii. Examine non-climate factors that aggravate or mitigate the impact of climate change, including geographic factors (e.g., proximity to coast and waterways, terrain), geologic factors (e.g., strength and erodibility of soils), watershed features (e.g., land use, state of degradation) and relevant socio-economic drivers.

iv. Assess the vulnerability of the subprojects to climate risk considering the combined effects of future climate change and related non-climate change factors.

v. Identify risk reduction measures, including follow-up assessments needed during the detailed design and engineering phase.

8. This assessment focuses on the vulnerability of representative subprojects under standard scenarios of climate change (RCP 4.5 and RCP 8.5) as used by MoNRE. It does not compare vulnerability on a with-project or without-project basis[2], but rather examines directly the vulnerability of the proposed subprojects based on their preliminary engineering designs, location and other relevant factors.

II. CLIMATE SENSITIVITY OF BIIG2 INFRASTRUCTURE TYPES

A. Critical Climate Parameters for BIIG2 Infrastructure

9. For roads, the critical climate parameter is precipitation in terms of volume and intensity, and their impact on occurrences of flooding and landslide depending on location. In combination with geology and geography, a related variable is soil moisture as it affects road foundation stability. Sea level rise has important implications for coastal roads particularly in relation to distance from coastline (scour risk) and height of embankments.

10. Hot days temperature is also an important consideration for road design, particularly for asphalt roads, due to its effect on stiffness of the pavement. The stiffness modulus of asphalt is affected by temperature. Migration/bleeding of liquid asphalt is a concern at sustained air temperatures above 32C. For concrete roads, the range of temperature variation determines the proper width of joints, including the composition of the joint sealants.

11. For coastal roads and flood embankments, sea level rise will be an important future determinant of the height of the embankments to provide sufficient clearance or freeboard (preferably reckoned from the level of the subbase) in relation to the high-water level induced by

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[2] The road subprojects mostly involve upgrading of existing roads. In adopting higher design standards (including drainage system), the upgraded roads are more climate-resilient.

tide and sea surge. Future levels will be higher because of sea level rise. Similarly, the level of jetties or piers for fishing ports and boat anchorages will be affected.

12. For causeways and bridges, the critical design parameter derived from precipitation and catchment characteristics is flood level which determines the required vertical clearance of the bridge deck or causeway top. The high-water level is estimated for a design frequency of occurrence (return period) depending on the type/category of bridge. The design level of the bridge then affects the positioning of abutments, height of the supporting pillars, and the height of the approach embankments.

13. For water supply projects, precipitation and temperature are critical parameters—precipitation and its seasonal distribution because, together with the characteristics of the watershed or groundwater system, it ultimately determines the reliable amount of water that can be extracted (dependable yield or safe yield). Temperature change is also important because it affects water demand including rate of water loss to evaporation. Time series data on maximum duration of consecutive dry days is a proxy indicator used to determine the probable recurrence interval of droughts and need for water storage (and other water conserving measures).

B. Effects of Climate Parameters on Infrastructure Performance and Durability

14. A main concern for roads under climate change threat is protection from water penetration and damage to the pavement and foundation (sub-base and subgrade). Foundation support is at risk if water saturation occurs, which is then reflected onto the pavement as cracks and deformations. Subgrade soils with high plasticity (e.g., clay) will decrease in strength once saturated. Saturation also reduces the amount of contact and interlock in the base/sub-base layers, so the aggregates move when repetitive load is applied. This leads to pavement deformations that contribute to accelerated deterioration. Water saturation can also cause road embankments to become unstable and for cut slopes to collapse on the pavement.

15. The road structure must be well drained to protect from the effects of excessive water penetration. Water will enter the surface through cracks, ruts and potholes. It can also enter laterally through unlined canals and even from the underlying water table through capillary action. Optimum pavement performance is achieved by preventing water entry in the first instance (through good surface drainage), and by removing any water that does enter through a well-designed subsurface drainage (adequate sub-base thickness and gravel aggregate sizing). Repairing damage to the subbase and subgrade generally costs more than water-proofing measures to ensure that no water enters the road structure.

16. Most of the road subprojects are to be asphalt-paved. The impact of temperature rise under climate change is primarily on the pavement through its influence on stiffness of the asphalt. Asphalt pavements flex with the base layer absorbing the load. If the asphalt layer flexes too much, strain is induced on the subbase and subgrade. Too much strain there causes fatigue cracking in the pavement. Higher temperatures also accelerate hardening of the bitumen, and causes the binder to become brittle resulting in increased incidence of surface cracking.

17. The bridges used in the road subprojects range from submersible spillways or causeways on low-lying areas, to beam-slab concrete bridges across small streams, and to multi-span river bridges exceeding 100 meters in length. The submersible crossings are vulnerable to increased depth and duration of flood levels under future climate change, rendering them impassable to traffic. Bridges are even more vulnerable if over-topped due to the force of the floodwater on the abutments and superstructure, and impact from floating debris.

18. Seasonal quantity and variability of rainfall affects the performance of water supply systems through an imbalance usually created by having too much water in the wet season and too little in the dry season. Thus, the distribution of rainfall over the year, in relation to demand, determines the need for, and sizing of, water storage facilities to even out the water availability. Rainfall intensity affects surface water quality through increased water turbidity and cost of treatment. Whereas water demand usually increases with higher temperature due to increased consumption and water loss to evaporation.

C. Effects of Ongoing Weather Variability and Extremes

19. Effects of weather variability and extremes under the current climate are evident in the representative subprojects. At the Anh Son district road 349 (representative subproject in Nghe An), the existing road is flooded 3 to 5 times per year for 2 to 3 days on average (maximum of 10 days) per event, effectively cutting off traffic. For 5 sections of the road, deep flooding occurrs during the rainy season, mainly due to overbank flow and backwater effect from the river system. At one section (Hamlet 3 at Thanh Son), the reported flood depth exceeds 5 meters. Many ditches and culverts have been buried in silt and flood debris. While such conditions are partly due to the lack of road maintenance and other non-climate factors (watershed condition), the effect of heavy rainfall events on flooding frequency and severity is evident.

20. At the Gio Linh – Cam Lo inter-district road (representative road in Quang Tri), the existing earth road is in very bad condition with many ruts and gullies--symptoms of chronic water damage to the road. Local flooding regularly cuts off road sections near streams and depressions, and existing spillway bridges are impassable for 2 to 3 days up to ten times during the rainy season, according to a resident. In the province itself, rainfall during the wettest months cause severe flooding, soil erosion and landslides.[3]

21. At the Bao Ninh – Hai Ninh coastal road (section one of three sections that form the representative project in Quang Binh), one culvert bridge section of the existing road has collapsed due to flooding in late October 2016. Persistent rains triggered scouring and collapse of the bridge foundation, abetted by the loose sand bed. Continuous rain for two days, totaling 248 mm in Dong Hoi City some 11 km north of the site, resulted in widespread flooding.[4]

22. In Nghe An where a flood embankment to protect a coastal community is proposed as an *additional* subproject, flooding in the site currently occurs 7 to 8 times per year between July and October, compared to 4 to 5 times per year 15 years ago according to commune informants.

23. At Can Loc district in Ha Tinh, a proposed water supply project will source water from an existing irrigation reservoir. Summer supply is deficient and rainy season flooding often occurs affecting water facilities.[5] Annual rainfall at Ha Tinh varies widely from 1,297 mm to 4390 mm. The range in monthly rainfall during 2012 was from 11 mm in January to 564 mm in October. Consequently, catchment discharges and river flows are variable—rainy season flows decline rapidly after the rains stop. During the dry season, tidal influence extends up from the estuary into the Nghen River. However, salinity intrusion is controlled through a salinity barrier. The barrier

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[3] Lai Vinh Cam. Soil erosion study by using RUSLE model: A case study in Quang Tri province, Central Viet Nam. VNU Journal of Science, Earth Sciences 27 (2011), 191-198.

[4] http://www.aljazeera.com/news/2016/11/vietnam-flooding-kills-central-provinces-161102082824596.html

[5] ADB PPTA 8957. Feasibility study for water supply systems for 7 communes in Loc Ha district and 2 communes in Can Loc district, Ha Tinh province. March 2017.

also provides the tidal variation that supplies water into the Nghen river upstream of the subproject site.

III. CLIMATE CHANGE PROJECTIONS FOR CRITICAL PARAMETERS

A. Climate Change Modeling and Database

24. Five regional climate models were used by MoNRE's Institute of Meteorology, Hydrology and Environment (IMHEN) to dynamically downscale and produce high-resolution simulations for Viet Nam based on 9 global climate models (GCM). Two sets of projections were completed using two IPCC climate change scenarios: RCP 4.5 (representing an optimistic scenario) and RCP 8.5 (pessimistic scenario).[6] We used this existing MoNRE climate change database for the assessment[7].

B. Projected Country-wide Climate Change and Sea Level Rise

25. Weather conditions that affect infrastructure performance are projected to intensify under future climate change. According to MoNRE, average annual temperatures throughout the country increased by 0.62°C from 1958 to 2014, at an average of approximately 0.1°C per decade.

26. Projected temperature increases are higher in the north. Under RCP 4.5, mid-century (2046-65) temperatures would increase by 1.3 to 1.7°C relative to 1986-2005, while under RCP 8.5, the increase is 1.8 to 2.3°C. Extreme temperatures are projected to increase in all climate zones. The number of hot days (maximum temperatures exceeding 35°C) show increasing trends in most parts of the country.

27. Rainfall is projected to increase under RCP 4.5 during 2016-2035 (early century), annual rainfall is projected to increase by 5 to 10% relative to 1986-2005. By mid-century, rainfall would increase 5 to 15% overall. For some coastal provinces in the North Delta and the central regions, the increase is likely to be up to 20%. Under RCP 8.5, the projected increase is of roughly the same magnitude. Projected changes in short-term (1-day and 5-day maximums) rainfall are higher than annual changes with projected increases of 10 to 70% relative to 1986-2005.

28. Sea levels at coastal monitoring stations in the period 1960-2014 rose by about 2.45 mm/yr. From 1993 to 2014, the rate of SLR had increased to 3.34 mm/yr. The largest increase in average sea level was found along the central coast at 4 mm/yr. Under RCP 4.5, the average sea level rise for coastal areas nationally is projected to be about 22 cm by mid-century whilst under RCP 8.5, the projected average SLR is 25 cm.[8]

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[6] Ministry of Environment and Natural Resources. Climate Change and Sea Level Rise Scenarios for Viet Nam. Hanoi, 2016. (The summary report is in English; the full report in Vietnamese.)

[7] Details of MoNRE's climate change database and how it was set up described in Annex A, which also provides a guide on interpreting the scenarios and modeling outputs.

[8] With 80% of models predicting in the range of 14 to 32 cm and 17 to 35 cm, respectively

C. Projected Climate Change in BIIG-2 Provinces for Critical Parameters

29. Based on the 50-year historical data (1961-2010), the annual temperature in the central coast region increased by 0.11 to 0.24°C per decade.[9] Most rainfall station observations showed either almost no change, or slight decreases, in annual rainfall. Annual maximum 1-day and 5-day rainfall, including number of very wet days, have not changed significantly for most stations in the region.

30. Under Scenario RCP 4.5, the mean value (multi-model) projections for the increase in average temperature across the 4 provinces is 0.6°C by early-century (2016-35), and 1.5°C by mid-century (2046-65). Under RCP 8.5, the corresponding projected change is 0.9°C and 1.9°C, respectively.

31. Although changes in average temperature look modest, the change in extreme temperatures are more significant. Heat wave occurrence, (defined as number of consecutive days with maximum temperatures exceeding 35°C), is projected to increase across all four provinces. The changes projected from 8 downscaling model-runs are summarized in Table 2.[10]

Table 2. Projected increases in heat wave duration (number of consecutive days with Tmax>35°C)

Province	Baseline No. of days	RCP 4.5		RCP 8.5	
		2016-2035	2046-2065	2016-2035	2046-2065
		(% of base line days)			
Ha Tinh	13	37	114	62	145
Nghe An	12	42	128	67	155
Quang Binh	17	28	97	47	122
Quang Tri	18	33	88	46	113

32. Most climate station observations show almost no change in annual rainfall based on records from 1961 to 2010. However, climate models project annual rainfall increase in coming decades for all provinces (relative to the reference period 1986-2005). Mean values (percentage increase) derived from climate modeling are shown in Table 3. The range of projections with reference to the 10% and 90% percentile values (i.e., 80% confidence interval) are shown in Annex B.

Table 3. Projected increase in annual rainfall (%)

Province	RCP 4.5		RCP 8.5	
	2016-35	2046-65	2016-35	2046-65
Nghe An	10.2	16.8	16.6	21.6
Ha Tinh	11.3	16.3	12.9	14.1
Quang Binh	10.1	12.6	10.8	14.1
Quang Tri	11.4	16.6	16.5	16.8

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[9] This refers to change across each decade, not the annual change within each decade.

[10] The 8 climate change simulation-runs adopted by MONRE were: CCAM-CCSM4, CCAM-CNRM-CM5, CCAM-GFDL-CM3, CCAM-NorESM1-M, clWRF-NorESM1-M, PRECIS-CNRM-CM5, PRECIS-GFDL-CM3, PRECIS-HadGEM2-ES. Three *regional climate models* were used to downscale GCMs: CCAM, clWRF and PRECIS. CCAM was used on 4 GCMs; clWRF was used on 1 GCM; and PRECIS was used on 3 GCMs.

33. Most additional rain is expected to be in the form of intense rainfall. Extreme rainfall events are projected to increase more significantly. Percentage changes, averaged from three modeling runs (or computational cases) using the regional climate model PRECIS,[11] are shown in Table 4 for the maximum one-day rainfall and the maximum five-day rainfall.

Table 4. Projected increase in extreme rainfall (%)

Province	Annual maximum one-day rainfall				Annual maximum five-day rainfall			
	RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	2016-35	2046-65	2016-35	2046-65	2016-35	2046-65	2016-35	2046-65
Nghe An	23	34	29	35	26	40	30	34
Ha Tinh	27	38	23	18	27	41	26	19
Quang Binh	31	35	21	26	25	35	21	24
Quang Tri	42	45	38	44	35	45	31	40

34. The coastal zone of the four provinces is covered by two sea level monitoring regions from Hon Dau near Hai Phong in the north to Deo Hai Van near Da Nang to the south. The average values of sea level rise projections from multiple models are shown in Table 5. The range of projections with reference to the 5% and 95% percentile values (i.e., 90% confidence interval) are shown in Annex B.

Table 5. Sea level rise projections (cm)

Scenario	Coastal region	2030	2050	2080	2100
RCP 4.5	Hon Dau - Deo Ngang	13	22	39	53
	Deo Ngang - Deo Hai Van	13	22	40	53
RCP 8.5	Hon Dau - Deo Ngang	13	25	50	72
	Deo Ngang - Deo Hai Van	13	25	50	72

Note: Deo Ngang is at the border of Ha Tinh and Quang Binh.

35. Storm surge is a rise in sea level due to the impact of a typhoon. In the coastal area between Nghe An and Ha Tinh, the observed highest storm surge was 400 cm. MoNRE has estimated that the highest storm surge than can occur in this coastal stretch is 450 cm. Between Quang Binh and Hue, the highest observed storm surge was 300 cm, and MoNRE’s estimate of the highest possible surge that can occur along this coast is 350 cm.

IV. NON-CLIMATE FACTORS CONTRIBUTING TO VULNERABILITY

A. Geographic Factors

36. The Bao Ninh – Hai Ninh coastal road in Quang Binh is parallel to the coast, around 150 meters to the high tide water line at the closest point, and is on generally low elevation. The road sits on a sandy foundation because of proximity to the sea. While sand is a strong foundation material when compacted and confined, it is easily erodible when exposed to moving water. In the existing road, a short section failed due to scouring of the foundation (supporting a box culvert

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[11] Of the 5 regional climate models used by MONRE to downscale various global climate models, PRECIS was found to have the best fit between baseline projections and historical data. A modeling run refers to a downscaling application of PRECIS to a global climate model. See Annex A. In this case, PRECIS was used to downscale 3 GCMs: CNRM-CM5, GFDL-CM3 and HadGEM2-ES. The tabulated values are the average from the three modeling runs.

bridge). In one spillway crossing, the apron below the culvert collapsed due to the weak support provided by the sand foundation.

37. A recent study on potential changes in longshore sediment transport (LST) along Viet Nam's coast due to climate change (based on model-predicted wave height, period and direction) reported that, for the coastal section at Quang Binh, there will be no change in the direction of the net sediment transport which will remain towards the north. However, the modeling predicted a 15% increase in net LST, equivalent to 170,000 cubic meters per year (by 2080-2100 relative to 1981-2000).[12] This implies potential changes in future coastal position which can affect the coastal roads and other infrastructure there.

38. At the Gio Linh – Cam Lo mountain road in Quang Tri, The existing earth road crosses areas with varying topography and agricultural land uses. Most of the road sections are on generally flat to undulating terrain. However, the 3km mid-section is hilly requiring cuts to form the road. The area's soil is susceptible to erosion, and mountain areas in the province experience landslides during heavy rains.[13]

39. At the Dinh Son – Anh Son mountain road in Nghe An, seasonal flooding at the various stream crossings is worsened by backwater effect from the nearby Lam River which runs roughly parallel to the road. The subgrade is clayey, which is susceptible to deformation when water-saturated.

40. In Ha Tinh, where the representative subproject is water supply, water availability from surface sources (rivers and springs) is undependable due—besides the wide seasonal variation in rainfall—to the nature of the watersheds. The upper basins are narrow and the streams are short, so that not enough water is stored underground to carry over as base flow during the dry season. Proposed use of an existing reservoir as source enhances resilience of water supply by its effect of carrying excess rain season water over to the dry season, i.e., mitigating the natural variability of water supply.

B. Other Factors

41. Development pressure on the coast is strong given the area's potential for tourism, aquaculture and economic zone development. However, improved infrastructure such as roads comes with the risk of encouraging people to further settle in areas vulnerable to future effects of sea level rise and climate hazards (e.g., sea surge). In Phuc Tho (Nghe An), for example, residents of a community bordering the river estuary are exposed to increasing frequency and severity of flooding and have petitioned the local government to build a flood embankment. On the other hand, building such embankments creates a sense of security that may encourage more development and settlement in inherently vulnerable locations.

42. Watershed modifications that increase the rate of runoff are also contributing to climate vulnerability. Along the Dinh Son – Anh Son and the Gio Linh – Cam Lo mountain roads, for

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[12] Ali Dastgheib, Johan Reyns, Supot Thammasittirong, Sutat Weesakul, Marcus Thatcher and Roshanka Ranasinghe. Variations in the Wave Climate and Sediment Transport Due to Climate Change along the Coast of Viet Nam. Journal of Marine Science and Engineering, 4:86, 2016

[13] Lai Vinh Cam. Soil erosion study by using RUSLE model: A case study in Quang Tri province, Central Viet Nam. VNU Journal of Science, Earth Sciences 27 (2011), 191-198.

example, surrounding areas are being developed for tree plantations and cash crops. Associated land clearing activities expose the soil to erosive rainfall.

43. A combination of changing climate and changing watershed conditions imply that future flows in rivers and streams will be different from what the historical data suggest. Such potential changes are not yet systematically integrated into the design of infrastructure. The design of road drainage systems, bridges and embankments generally use unadjusted historical data on rainfall and streamflow. However, for any design return period, the magnitude of the future event is likely be higher than the past, leading to potentially under-designed and vulnerable structures.

V. VULNERABILITY ASSESSMENT OF REPRESENTATIVE SUBPROJECTS

A. Vulnerability of Mountain Road Subprojects

1. Gio Linh – Cam Lo Road, Quang Tri

44. The Gio Linh – Cam Lo road at Quang Tri was originally planned by Department of Transport (DoT) to be upgraded to Category 5 (mountain road), but because of the higher volume of traffic projected over the road's service life the forecast Passenger Car Unit (PCU) loading requires it, under DoT standards, to be upgraded to Category 4 effectively making it more climate resilient. This is because the engineering specifications for a Category 4 road (based on TCVM 4054 dated 2005) provide for better drainage (lined ditches and more closely spaced cross culverts), stronger foundation (thicker aggregate base and sub-base), and a wider surface on which to spread vehicle loads, especially from the projected truck traffic.

45. The preliminary engineering drawings show rather steep side slopes of cuts at the central hilly section of the road, at 1:0.5, which according to the DPI consultant for the road complies with TCVN 4054 (2005) for cuts into (supposedly) rock formations. The geology of the area will be verified during DED, given the erodible nature of soils in the area and exposure to heavy seasonal rainfall.

46. There are currently 8 spillway road crossings over shallow streams or localized depressions. They are essentially concrete embankments with culvert openings to pass normal streamflow, but during high floods water over tops the spillways. Currently, some of the spillways are impassable for up to 3 days during very heavy rains. These are to be replaced by higher box culvert bridges with larger apertures or openings to pass floodwater; and in case of overtopping, to shorten the period when the spillways are impassable.

47. In addition to the spillways, there are 4 existing small bridges with lengths of up to 24 meters. These are to be improved or converted to concrete beam-slab bridges, and one is to be widened by adding an additional lane. The design of these small bridges follows TCN 272 (2005) with the design discharge set at P4% (or the 25-year flood).

48. In the case of the small bridge at KM - 16+934, the vertical clearance of 0.73 m above the calculated 25-year flood. However, the highest recorded flood there is around 0.5 meter higher than the design elevation of the bridge deck. The bridge at KM 18 has clearance above the 25-year flood, but the level of the deck is lower than the highest recorded flood by at least 1 meter. With the projected increased future rainfall, overtopping of these small bridges and related debris-damage is a significant risk. Bridge levels may need to be raised higher than in the preliminary plan. This needs to be checked during the DED with reference to CC-adjusted hydro-climate data.

49. The longest bridge, which is to be built across the Hieu River, is 132 m long. It is arched so as not to obstruct river navigation. The design elevation of the deck (measured at the abutment) is at 16 m, whereas the highest recorded flood level was at 12.8 m in 2009 (clearance of 3.2 m). The calculated P1% (100-year) flood level is at 13.5 m (clearance of 2.5 m).

50. Referring to TCN 272 (2005) which specifies design standards for permanent bridges, the vertical clearance between the 100-year flood and the lowest level of the bridge deck should be at least 0.5 m. This requirement is met by the design of this bridge. However, the 100-year flood level was estimated based on only 8 years of data (2009-2016). This should be verified during DED. The highest recorded flood level occurred in 2009, the same year that river gauging apparently started. It is possible that there may have been higher unrecorded flood levels prior to 2009. In view of combined climate change and land use change, the true level of the 100-year flood is likely to be higher. Fortunately, the present clearance of 2.5 to 3.2 m gives adequate margin for risk.

51. Overall, the decision to upgrade the road to Category 4 rather than to Category 5 already increases its climate resilience, as noted earlier. Nevertheless, there remain aspects of the site and the project design that make the subproject vulnerable to climate risk: (i) cut areas in the mid-section of the road will be vulnerable to landslides under climate change, (ii) erodible soils along the route require care in their use as embankment fill near waterways; and (iii) the submersible bridges if merely improved but maintained at their present elevations may be subject to more frequent and deeper/severe flooding as well as debris damage under combined climate change and watershed alterations. These concerns should be examined more closely during DED.

2. Dinh Son – Anh Son Road, Nghe An

52. A significant climate risk is the design clearance of the bridge that will replace the present causeway. The bridge deck is to be raised about 7 m above the existing causeway top (slightly above the level of the existing foot bridge), corresponding to a design clearance of 1 m above the historical maximum flood which occurred in 1988. This flood is reportedly equivalent to the 100-year event, and serves as the P1% (1 in 100 flood event) design flood. This is same criteria used for the recently constructed bridge near NH7 junction. During DED, the magnitude and level associated with this design flood, which was based on historical records, should be verified with reference to CC-adjusted data.

53. A further risk leading to vulnerability is increased rainfall and the impact on of road drainage. Soil type in the area is clayey which is prone to deformation when saturated (water entering from cracks/ruts or unlined ditches) and subjected to dynamic loading, leading to reflected pavement cracks that deteriorate to potholes, which then collect even more water creating a vicious cycle.

54. Design should be based on keeping the pavement and road base impervious to water. This is not always possible but needs to be maximized through proper surface drainage and internal drainage. The preliminary design addresses this by adding a 25-cm aggregate sub-base layer and provisioning for lined side drains. The existing cross drains (culverts) are clogged or buried and, because they are only 75 cm wide, are hard to clean. Use of larger culverts should be considered in the DED.

B. Vulnerability of Coastal Road Subprojects

3. Bao Ninh – Hai Ninh Coastal Road, Quang Binh

55. When re-graded and surfaced, the finished 10.6 km coastal road in Quang Binh will have a road-top elevation ranging from 4.1 to 9.9 m above mean sea level. The consultants for the Dong Hoi master plan (2012) recommended that construction projects be built above at least 2.3 m elevation.[14] The coastal road meets this criterion; its lowest elevation (pavement top) being 1.8 m above this critical elevation--although if this in relation to the sub-base level the safety margin is around 1.5 meter which is still sufficient.

56. MoNRE's median projection of sea level rise in this coastal region, under a worst-case climate scenario RCP 8.5, is 25 cm by 2050. At this higher mean sea level, the road's lowest section will be at 3.85 m elevation. During high tide (1 meter above mean sea level at P2% frequency) the high-water line at this lowest section will be 2.85 m below the pavement and around 2.5 m below the level of the sub-base.

57. According to MoNRE, the highest observed storm surge in the Quang Binh to Hue coast was 3 m. With climate change, the estimated highest storm surge that can occur along that coast is estimated at 3.5 m (presumably already accounting for high tide effect). This is about 0.5 m short of the road's pavement elevation.

58. The road therefore appears to have a margin of safety against effects of sea level rise.

59. The impact of extreme precipitation under climate change may have more significant future impact. The road sits on a sandy foundation because of proximity to the sea. While sand is a strong foundation material when compacted and confined, it is easily erodible when exposed to moving water due to lack of cohesion. In the existing road, a short section failed apparently due to scouring of the foundation supporting a box culvert crossing during a flood in 2016. In one of the spillway crossings, the apron below the culvert also collapsed apparently due to the weak support and anchoring provided by the sand foundation.

60. There are 15 existing culverts which will be maintained, and 28 new ones will be added. All the new culverts will be box-type ranging in size (width) from 75 cm to 200 cm. Roadside ditches will be lined with rip-rap, with top width of 120 cm and 0.4 m depth (trapezoidal cross section). In sections where the road crosses sand dunes, the exposed roadside will be protected by a 1.2 m high concrete wall to protect against sand slides.

61. Overall, even though the road's coastal alignment exposes it to potential adverse effects of sea level rise and typhoon surges, the design elevation of the road provides a margin of safety—0.5 m above the highest possible surge level--for at least up to the 2030s. However, even though the streams crossed by the road are small, projected increased rainfall intensity combined with the inherently loose/sandy characteristic of the road foundation make culverts vulnerable to scour and collapse. These are already addressed in the preliminary engineering design minimizing the risk.

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[14] Quang Binh Department of Construction. *General Plan for Adjusting Construction of Dong Hoi City and Adjacent Areas up to 2020, and Vision to 2035*. Dong Hoi, June 2012 (Vietnamese version). The Consultant was NIKKEN Sekkei Civil Engineering Ltd.

C. Vulnerability of Water Supply Infrastructure

4. Water Supply System, Ha Tinh

62. There are two water supply networks proposed under this subproject. The southern network will supply 2,500 m^3/day in Loc Ha district, whereas the northern network will supply 7,000 m^3/day in Can Loc district. Water for the southern network is to be taken from the recently installed main line that connects to the city's water supply. The current supply is not considered vulnerable with the subproject connecting a new 162km network to the existing network through a pump station and additional water tanks to cover down time in supply maintenance.

63. The larger northern network sources water from the Cu Lay reservoir used for irrigation.[15] In doing so, the water diverted from irrigators will be supplied through increased water provision from the Nghen river (at CG Cao Cau) using an existing water transfer canal. At present, the usable annual water volume from the reservoir—available 75% of the time--is 17.6 million cubic meters (MCM), of which 15.06 MCM is used for irrigation and 2 MCM goes to evaporation loss. Since an estimated 2.55 MCM is required to supply the new drinking water supply network, a deficit of at least 2 MCM for irrigation needs to be sourced elsewhere.[16]

64. In terms of vulnerability to present and future climate variability and extremes, use of the reservoir enhances resilience of the new water supply system. It evens out water availability over the year, which is important given the natural high variability and extremes of rainfall and streamflow in the area. At present, only three months (September to November) account for 78% of the reservoir inflow based on records from September 2015 to August 2016. This high variability is likely to become more pronounced with climate change, even as total annual rainfall is projected to increase.

65. According to MoNRE's climate change projections, annual rainfall in Ha Tinh is projected to increase by 11.3% by the 2030s, and by 16.3% by mid-century. But much of this increase will occur during the very rainy months when there is already too much water for the reservoir to capture/store (with the excess water spilled). Additional rainfall during months when the reservoir can capture water for storage would partly be offset by future increased evaporation rates due to projected higher temperatures and heat wave duration.

66. The resilience (to supply variability) of the drinking water system is enhanced by the reservoir, with the water supply scheme having priority over irrigation in case of water shortages. Vulnerability is *shifted* to the irrigation system because it must replace the diverted reservoir supply and any shortages through pumping from the Nghen River. Even though the river has adequate average water flows, it is subject to tidal effects and hence to salinity intrusion during the dry season. Tide and salinity intrusion is increased by climate change through sea level rise. For the Nghen River system a salinity barrier already exists. As such there is no expected risk from saline intrusion or tidal surge.

D. Vulnerability of Other Additional Infrastructure

5. Phuc Tho Dyke, Nghe An

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[15] The reservoir was constructed in 1972 under a World Bank project and is being managed by the Northern Ha Tinh Irrigation Limited Liability Company; it was upgraded in 2001-02. The catchment area is 14.8 sq km.

[16] The irrigation shortfall will be compensated by taking water from the Nghen River to supply the existing irrigation command area served by the Cu Lay Reservoir.

67. Main CC issue is the preliminary design freeboard of the dyke, i.e., the difference between the P5% high water level or 20-year high water level (per TCVN 9902:2013) and the top of the dyke.

68. The 1.9 km earth dyke is designed to be 3.5m wide at top (concrete pavement), and around 20 m at base, with its top set at 4 m above (historical) mean sea level (amsl).[17] The dyke's riverside slope, at 1:2.5, will be protected by stone encased in a grid of reinforced concrete frame, with the toe anchored on the river bed. The inner side, at 1:2 slope, will be grass-covered. The dyke will provide protection from flooding. Old growth mangroves, though thin, line the river and will provide protection against wave action and dyke toe scouring.

69. The area to be protected lies between the main road (upgraded in 2007, and itself originally a dyke) and the river. In it resides 530 households. Flooding in this area currently occurs 7 to 8 times per year (between July and October), compared to 4 to 5 times per year 15 years ago, according to commune informants. Almost all households get flooded. The flood depth is around 2 m at street level (on the river side), and 1 to 1.2 m inside the houses.

70. There are 4 water level gauging stations along the river, with records dating back to 1954. The highest water level was recorded at Yen Thuong, farthest inland, in 1978 at 12.38 m. Near the mouth of the river, at Cua Hoi, the highest water level recorded was on 19 September 1989 at 4.7 m. This corresponds to a frequency of 0.5% or roughly 200-year return period based on the historical record of annual maximum water levels at that station. Phuc Tho is located 6 km inland, so any sea surge-related flooding would have been attenuated considerably by the time it reaches Phuc Tho. At Phuc Tho, the 20-year (P5%) water level was calculated by DPI at 3.31 m amsl.

71. According to TCVN 9902:2013, the dyke top must be set based on the P5% (equaled or exceeded once in 20 years on average) historical high- water level, plus allowances for wave height in the river, subsidence of the dyke, and a safety margin. This works out to a value of 3.98 m according to DPI's calculations, rounded off in the design drawings to 4 m. If the P5% flood is at 3.3 m, the design allowance for freeboard is 0.7 m (4 minus 3.3).

72. According to MoNRE's modeling-based projections, mean sea level rise for the north-central provinces is 8 to 18 cm by 2030s, and 13 to 32 cm by 2050s (with 90% confidence based on the ensemble of climate models) for scenario RCP 4.5. For RCP 8.5, the projected increase in average sea level is 9 to 18 cm by 2030s and 17 to 35 cm by 2050s. Using the median of these projections, the dyke freeboard is reduced to just 57 cm in the 2030s for both RCP 4.5 and 8.5. However, this does not yet account for probably increases in sea surge height due to CC, which according to MoNRE could increase by up to 50 cm. Using this probability argument, there is room to re-assess the dyke top level as currently designed if future climate is accounted for.[18]

6. Upgrading of Fishing Port, Quang Binh

73. The most relevant climate change parameter is flooding as determined by extreme precipitation and sea surge events, through its impact on port operations by way of severe disruption and water damage to facilities (e.g., power generators, cooling units). Projected future increase in hot days (maximum temperature and duration of heat waves) may also affect fish

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[17] This is also the level of the main road which runs roughly parallel to the proposed dyke. Hereinafter, reference to elevation (meters) means above mean sea level.

[18] Note that this vulnerability will also apply to the adjacent main road which is on the same top elevation as that of the dyke.

quality (addressed in the port upgrading plan through a covered fish handling area and improved fish storage.

74. To allow boats to dock during low tide, the waterfront will be dredged. But sand transport and deposition below the jetty could become a recurrent problem with adverse climate change effect on currents and flows in and out of the estuary.[19]

75. The jetty is to be expanded/lengthened, but it's present elevation will be maintained at 2.1 m (which is also the level of the access road). The highest water recorded at the port's location was 1.5 m in 2010, hence a clearance of 0.6 m up to the top of the jetty. The fish port has reportedly never been flooded since starting operation in 2001. It does not mean though that future flooding is ruled out. Local informants could not recall if any flooding in the area occurred prior to 2001. There is a record of river flood levels from 1959 to 2005, which can be used during feasibility study to estimate the return period of the 2010 event.

76. Historical data (provided by DPI's consultant) show the highest tide level at 1.1 m, corresponding to P1% frequency or 100-year return period. At 50-yr frequency, the level is at 1 m; and at 20-yr frequency it is 0.86 m. Thus, the 50-yr high tide water level is 1.1 m below the level of the jetty (i.e., 2.1 – 1.0 m). The worst-case flooding scenario is a river flood occurring at high tide and combined with typhoon-induced sea surge.

77. Sea level rise projected for the Deo Ngang to Deo Hai Van coastal region is between 8 to 18 cm by 2030, and 13 to 31 cm by 2050 under scenario RCP 4.5 (with 95% confidence based on models). For RCP 8.5 the projected SLR is 9 to 18 cm by 2030 and 17 to 35 cm by 2050. If we take the median projection for the RCP 8.5 scenario, sea level rise is 13 cm by 2030 and 25 cm by 2050.

78. According to MoNRE, the highest observed storm surge in the Quang Binh to Hue coastal area was 3 m. With climate change, the estimated highest storm surge that can occur along that coast is estimated by MoNRE at 3.5 m.

79. The jetty's present 2.1 m elevation is equivalent to 1.85 m by mid-century (considering the 0.25 m projected SLR under RCP 8.5). If tidal range is unchanged, the 50-yr high tide level will then be at around 0.75 m below the jetty by mid-century (compared to present 1.1 m). That represents the allowance for flooding if it coincided with high tide.

80. Vital port facilities are to be upgraded atop raised floors, according to the plan: at 3.2 m for the power generators (i.e., 1.7 m above highest recorded water level), and 2.4 m for both the fish processing house and fish storage area (0.9 m above highest recorded water level). The power generators are above the highest observed storm surge level in that coastal region (3 m), but still 30 cm below the highest storm surge that, according to MoNRE, can occur with climate change.

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[19] Ali Dastgheib, *et al*. Variations in the Wave Climate and Sediment Transport Due to Climate Change along the Coast of Viet Nam. Journal of Marine Science and Engineering, 4:86, 2016.

VI. ADAPTATION MEASURES

A. Roads and Bridges

81. The preliminary engineering specifications for the road infrastructure components (embankment heights, bridge heights, drainage system) are based on historical hydro-climate records, need to be re-visited during detailed engineering and design with a view to determining of the need to adjust the design to incorporate projected climate change effects on the climatic events that define P1, P2, P4 and P5 magnitudes.

82. It is important to assess the probably change in maximum rainfall intensities between the historical period and in the future (at least up to 2030s). Essentially, what may be expected under various climate change scenarios is for extreme rainfall events to increase in magnitude for any specified return-period, or conversely for the return periods to be shorter for any given an extreme rainfall event. Results can be factored into empirical equations or hydro-dynamic models to estimate probable changes in peak flows and flood levels.

83. For the **Gio Linh – Cam Lo mountain road** geological tests during detailed design, will need to verify the need for stabilization of road cuts at the hilly mid-section of the road alignment. Adaptations may involve cutting back vulnerable slopes to reduce steepness, reinforcing critical sections, supporting with retaining structures or landslide guard walls, and reforming the cut areas with surface soil layer and vegetation cover. The inclusion of bioengineering solutions should be incorporated into the DED terms of reference.

84. At the other sections of this road where the terrain is flat to undulating, fill for building up the road embankment near waterways should not use the erodible (sandy) soil from the site. This applies to locations near culverts and spillway bridges where flowing water can initiate scouring—and in view of the projected future increased intensity of rainfall and volume of stream flows.

85. Ditches should have discharge outlets at their ends to keep the canals from merely impounding drainage water than may penetrate through cracks into the road foundation. The pavement should be maintained to prevent cracks and potholes from forming/enlarging, as these allow water to penetrate the road structure and progressively weaken the foundation.

86. For the **Dinh Son – Anh Son mountain road**, the new bridge that will replace the causeway will be about 7 meters higher than the present causeway top; hence the bridge will require higher approach embankments on each side to achieve the desired bridge height. The embankment slopes should be protected from erosion, and the base protected from scouring because of proximity to the perennially flooded river.

87. The old causeway there may need to be demolished after the new bridge is constructed to remove its water-raising dam effect, as this can raise flood levels to be higher and to weaken the base of the high embankments approaching the bridge.

88. Cross drains should be of bigger diameters (at least 1 meter) to facilitate cleaning and removal of soil deposits and debris.

89. The PPTA feasibility identified the following measures for climate resilience: (i) sufficiency of road embankment height; (ii) adequacy of vertical clearance for bridges; (iii) lining of road side drainage especially along hills; (iv) improvement of drainage on valley side to reduce erosion

effect; (v) management of slope drainage; (vi) enhancement of road surface drainage by paving of shoulders, and (vii) related erosion control measures.

90. For the **Bao Ninh – Hai Ninh coastal road**, fortifying especially the culvert sections in contact with fast-flowing water will be important, particularly their foundation, aprons and wing walls, as this is where the water can undermine the structures. With projected more intense future rainfall and stream discharge, water-damage to the road in this way appears to be the most significant risk. The preliminary design already incorporates extended culvert aprons with anchor toes to prevent scouring and weakening of the culvert bedding and the area surrounding the culvert placement.

91. On-site sand is planned to be used as material for the core fill in road sections where a low embankment is needed to attain grade. The sand fill is to be encased in compacted earth, 1 meter thick. It is important to prevent the sand core/fill from being exposed to moving water, as this will initiate a progressive collapse of the road base.[20]

92. Pavement surfacing should be made resistant to water penetration to prevent the underlying foundation from becoming saturated. Based on follow-on geological survey work during DED, concrete pavement should be considered in low-lying areas where the road structure is vulnerable to water penetration. Traffic loading is the most important factor influencing pavement performance; saturated soil loses its ability to adequately support traffic loads and leads to premature pavement failure.

93. Proper compaction and moisture conditions during construction, quality of asphalt mix and gravel materials, and accurate layer thickness (after compaction) are important for durable pavement performance. This requires good inspection and quality control procedures during construction. During road operation, pavement cracks and potholes should not be left to deteriorate and allow water to penetrate the road structure—given future projected climate conditions characterized by heavier rainfall.

94. For the road pavements, the detailed design needs to reflect the sensitivity of asphalt pavement stiffness to high temperatures, including potential problems with migration/bleeding of liquid asphalt under prolonged hot weather, the quality of asphalt material used in road construction and maintenance is an important resilience measure. Heat wave duration is projected to increase. Detailed design work on the roads should consider and include developments in asphalt technology to check for modified binders that improve the performance of asphalt under increasingly hot weather.[21]

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[20] For road sections that pass through irrigated rice paddy areas and areas with high water table, the height of the road embankment should be checked for the extent capillary rise that may reach the level of the subgrade and compromise foundation stability.

[21] According to MONRE's climate projections for Ha Tinh, the duration of consecutive days with maximum temperatures exceeding 35°C is projected to increase by 37% under RCP 4.5 by 2030s, and under RCP 8.5 by 62%

B. Water Supply and Irrigation

95. Even though it is already under protection status, the Cu Lay reservoir for the **Ha Tinh water supply subproject** at Can Loc district should be prevented from excessive silting and loss of usable storage by proper management of the 14.8 sq km catchment. Adequate vegetation cover must be maintained to protect from projected future increase in rainfall intensity, including measures to reduce erosivity of streams through check dams and sediment basins to keep eroded soil from reaching the reservoir.

96. Erosion control measures for reservoir catchment maintenance are vital because projected increases in future rainfall intensity are quite considerable. According to MoNRE's climate change projections for Ha Tinh, the annual maximum one-day rainfall is projected to increase by 27% in the 2030s. The same magnitude of increase is projected for the 5-day annual maximum rainfall.

97. For the irrigation system which will absorb any future shortages of water supply from the Cu Lay reservoir, resilience to future water scarcity requires thinking beyond new supply measures. Adaptation should combine these with measures to increase water use productivity/efficiency. Numerous technical innovations and management measures are available that can improve the efficiency of water use for irrigated agriculture (e.g., lining of canals to reduce seepage, irrigation scheduling to prevent farmers from over-irrigating, and improved rice planting and irrigation methods through *system of rice intensification*, among others).

C. Other Infrastructure

98. For the two additional coastal infrastructure subprojects (river flood embankment and fish port) the clearance of vital components or structures above high water is an important climate change consideration.

99. Historical maximum flood levels are unlikely to provide reliable basis for determining design elevations (e.g., flood embankment tops, jetties) due to projected significant increase in future rainfall intensity (and consequently, river flooding) in addition to sea level rise and typhoon-induced sea surge. Future maximum flood levels are likely to be higher than magnitudes and frequencies derived primarily from historical data. The risk of using unadjusted hydro-climate data to estimate extreme events and corresponding flood levels for design purposes is that the structures would likely be under-designed and vulnerable to more frequent disruption and damage during operation.

100. Overall, it is important to ensure that BIIG2 infrastructure development is not planned "as-usual". Investment decisions must be made robust to risks of future climate change (and its interaction with other change drivers, such as land use change and watershed degradation.).

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ANNEX A: CLIMATE CHANGE DATABASE

A. Climate Modeling Principles

1. Assessing exposure to climate change hazards depends on predicting the direction and magnitude of climate change over a long period. Climate projections are based on plausible scenarios of what future greenhouse gas emissions will be like, as driven by population and economic development patterns. Despite significant advances in scientific understanding and climate modeling techniques, however, climate projections cannot preclude uncertainty. Projections derived from models, no matter how advanced, are not to be regarded as predictions of actual future climate. Rather, such projections provide simulations of future climate under a variety of hypothetical development and greenhouse gas (GHG) emissions scenarios and global mitigation policies.

2. Uncertainty in climate projections is managed by using climate models that capture well a region's dominant climate features and by not relying on just one model. Another aim is to quantify uncertainty so that the range of probable outcomes can be expressed probabilistically. This is done by using an ensemble of models. By producing a range of projections, the ensemble enables statistical analysis to be applied.

3. Projections are driven by assumptions and should therefore be interpreted properly and with caution considering the unavoidable uncertainty that remains. It is unwise, however, to wait for the uncertainty to disappear.

B. Global Climate Models Used

4. Coupled Atmosphere-Ocean General Circulation Models (GCMs) are used to project climate change. Such models simulate the processes, interactions and feedback loops between components of the global climate system they are typically run with low spatial resolutions (more than 200 km).

5. The World Climate Research Program develops global climate projections through its Coupled Model Intercomparison Project (CMIP) roughly every 5 to 7 years. These projections are used by the Intergovernmental Panel on Climate Change (IPCC) to prepare periodic assessment reports. The fourth assessment report was issued in 2007, based on findings from the CMIP Phase 3 family of climate models. During 2012-2013, WCRP released global climate projections from CMIP phase 5 modeling (or CMIP5), and these became the basis for preparing the fifth IPCC assessment report.

6. Although increasingly powerful computers are enabling a new generation of GCMs to produce high-resolution projections, outputs from most existing GCMs are too coarse for use at sub-regional levels, especially in areas with rugged topography. For realistic assessments of climate change impacts, higher-resolution information is needed.

7. Downscaling or regionalization techniques allow spatial refinement of existing GCM outputs. These techniques add fine-scale information to a parent GCM's low-resolution projections, and in doing so can resolve features down to a scale of 50 km or less. Such downscaling enables more precise representation of geographic features, such as mountain topographies and river basins – hence the projections are more useful for planning.

C. GCM Downscaling Methods

8. Two methods are available for downscaling GCMs: dynamical downscaling and statistical downscaling. In dynamical downscaling, a regional climate model (e.g., CCAM which was used by CSIRO for Viet Nam) is run for a delineated area in which the boundary conditions are generated or "driven" by a parent GCM. Since this method of downscaling is based on physical laws (rather than statistical properties of historical climate) it has the advantage of being able to produce a large suite of climate variables. The disadvantage is that it is computationally very demanding which limits the number of models that can be downscaled. For robust analysis of climate change uncertainty, it is preferable to use a set or ensemble of GCMs.

9. The other downscaling method uses empirical statistical methods. Since it is not based on physical laws, statistical downscaling is not as computationally demanding as dynamical downscaling; it can be applied to a set or ensemble of GCM simulations, enabling quantification of consensus which can serve as basis for assigning confidence in the projections.

10. All climate projections are adjusted to better match the statistical properties of the observed climate—a process known as "bias correction." This correction is done so that the climate simulation for the historical period statistically matches the actual observations. The correction factor derived is then applied to the future projections from the climate model.

D. Climate Change Scenarios

11. Scenarios used in climate modeling are primarily images of alternative futures. They are neither predictions nor forecasts (unlike weather forecasts). Rather, each climate scenario is one alternative picture of how the future might unfold, specifically in terms of greenhouse gas emissions and global policy responses. It is important to test all plausible scenarios, including the worst possible case, to come with robust plans for adaptation.

12. Emission scenarios used in climate change modeling are prescribed by the Inter-Governmental Panel of Climate Change (IPCC). An earlier set of so-called "SRES scenarios", used as basis for the Fourth Assessment Report of the IPCC in 2007, explored uncertainties in global socio-economic development trends that drive future greenhouse gas emissions.[22]

13. After 2007, new scenarios were developed provided flexibility in exploring the influence of policy choices, specifically regarding mitigating greenhouse gas emissions and corresponding total radiative forcing, defined as the difference of the solar energy absorbed by the Earth and the energy radiated back to space. The new scenarios, termed Representative Concentration Pathways (RCPs), were developed by the IPCC and are identified by their total radiative forcing, measured in watts per square meter (W/m^2) in year 2100 relative to 1750. Essentially, these

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[22] The three previous SRES scenarios were: **A2**: Describes a very heterogeneous world; economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than other storylines. **A1B**: Depicts technological change in the global energy system that is balanced, i.e., not relying too heavily on one energy source; global population peaks during mid-century and declines thereafter, accompanied by rapid introduction of more efficient technologies. **B1**: Describes a convergent world with global population peaking in mid-century and declines thereafter, accompanied by rapid change in economic structures toward a service and information economy, and associated with reductions in material intensity and introduction of clean- and resource-efficient technologies.

scenarios describe the degree in which GHG emissions are actively mitigated, stabilized, or increased.

14. The RCP scenarios guide current climate modeling work. Together, four RCPs span the range of plausible radiative forcing values from 2.6 to 8.5 W/m2. The scenarios are named according to their radiative forcings, with one scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5 and RCP6) and one very high emission scenario (RCP8.5). Note, by way of perspective, that the global net effect of human activities since 1750 has been estimated as being equivalent to a radiative forcing of 0.6 to 2.4 W/m^2.

15. The climate models used as basis for the IPCC Fifth Assessment Report issued in 2013 were run using the new set of RCP scenarios. Again, the aim was to generate projections that more directly reflect global policy choices for mitigating GHG emissions. Table 6 shows these new scenarios and the corresponding radiative forcing, CO_2 concentration, and representative climate policy.

Table 6. Latest Scenarios Used in the IPCC Fifth Assessment Report (2013)

RCP Scenarios	Radiative Forcing (W/m^2)	Projected CO_2 atmospheric concentration by 2100	Representative Climate Policy
RCP 2.6	2.6	421	Mitigation
RCP 4.5	4.5	538	Stabilization
RCP 6.0	6.0	670	Stabilization
RCP 8.5	8.0	936	Business as usual

Source: IPCC (2013)

RCP = representative concentration pathway, CO_2 = carbon dioxide, W = watts, m^2 = square meter

16. RCPs, in a strict sense, cannot be compared with the earlier SRES scenarios. Nonetheless, scenarios A1B and B1 may be equated approximately to the two medium stabilization pathways, RCP6 and RCP4.5, respectively. A2 can be approximately equated to RCP8.5 which is the high emissions pathway. Both sets of scenarios are relevant for producing climate change projections.

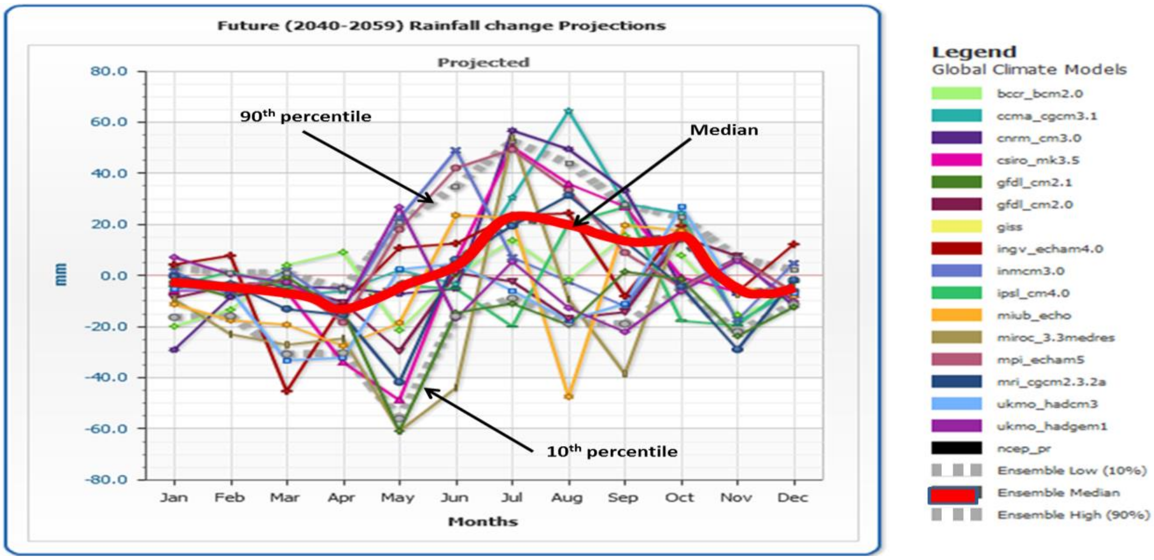
17. Note that there is no preferred climate change scenario. The IPCC does not provide suggestions on which SRES or RCP scenario pathway is more likely. Hence, no assumptions are made in climate change impact studies about the most probable future outcome. Rather, a range of scenarios representing high and low greenhouse gas emissions (often described as pessimistic and optimistic scenarios) should be included in the climate change simulations and used to test the robustness of adaptation measures.

E. MoNRE Climate Change Database for Viet Nam

18. Regional climate models were by MoNREMoNRE's Institute of Meteorology, Hydrology and Environment, with support from CSIRO/AusAid, to produce high-resolution simulations for Viet Nam using the latest available GCM simulations from the CMIP5 family of models. For the 2016 MoNRE report, state of the art results of 9 global climate models (under CMIP5 project) were used, namely: NorESM1-M, CNRM-CM5, GFDL-CM3, HadGEM2-ES, ACCESS1-0, MPI-ESM-LR, NCARSST, HadGEM2-SST and GFDL-SST.

19. Dynamical downscaling (as explained above) was done using five high-resolution regional climate models, namely: (i) the AGCM/MRI model from Japan Meteorological Agency (JMA), (ii) the PRECIS model from the UK MetOffice, (iii) the CCAM model from CSIRO - Australia, (iv) the RegCM model from ICTP - Italy and the clWRF model from Santander Meteorology Group - Spain. There were 16 computational cases (model-runs) in total. Statistical methods were applied for bias correction of the model output based on the observed data to minimize the bias of model results. See Table 7.

20. Likelihood levels in terms of percentile were estimated for climate change and sea level rise projections based on multiple models. In such model ensemble analysis, the multiple climate model results are aggregated using percentile ranking.



Source: World Bank Climate Portal. For illustration purposes only.

21. As illustrated above, this maps out the 10, 20, 50, 80 and 90th percentiles. That is, the 10th percentile means that 90% of the models predict values equal to or higher than the corresponding percentile value. At the other end, the 90th percentile means that 10% of the models predict values equal to or higher than the corresponding percentile value. Hence, one can say that there is an 80% likelihood that the actual value falls between the 10th and 90th percentile. Percentile values are used to assess the range of projections from the different models and to quantify uncertainty, i.e., based on the degree of agreement among models.

Table 7. Models Used in Setting up the Climate Change Database

Dynamical downscaling model	**Resolution and area coverage**	**Modeling organization**	**GCM Source**
clWRF	30 km, 3.5-27oN and 97.5-116oE	NCAR, NCEP, FSL, AFWA	NorESM1-M
PRECIS	25 km, 6.5-25oN and 99.5-115oE	Hadley - UK	CNRM-CM5 GFDL-CM3 HadGEM2-ES
CCAM	10 km, 5-30oN and 98-115oE	CSIRO, Australia	ACCESS1-0 CCSM4 CNRM-CM5

Dynamical downscaling model	Resolution and area coverage	Modeling organization	GCM Source
			GFDL-CM3 MPI-ESM-LR NorESM1-M
RegCM	20 km, 6.5-30oN and 99.5-119.5oE	Abdus Salam International Centre for Theoretical Physics (ICTP), Italy	ACCESS1-0 NorESM1-M
AGCM/MRI	20 km covering entire globe	JMA, Japan	NCAR-SST HadGEM2-SST GFDL-SST SST ensembles

22. An earlier climate change study conducted by INHEM, with support from CSIRO, used 6 GCMs that were selected based on their ability to realistically capture current climate and climate features such as El Niño-Southern Oscillation (ENSO): CNRM-CM5, CCSM4, NorESM1-M, ACCESS1.0, MPI-ESM-LR and GFDL-CM3. The RCMs used in the study were CSIRO's Conformal-Cubic Atmospheric Model (CCAM), RegCM4.2 (developed by ICTP in Trieste, Italy), and the UK Met Office's Providing Regional Climates for Impacts Studies (PRECIS) model.

23. A two-step method was used to generate the high-resolution regional climate simulations applying dynamical downscaling. First, data from the GCMs (approximately 200 km resolution) were used as input into an RCM run globally at finer resolution (50 or 100 km, depending on the regional model used in the next step). Then data from this simulation were used as input into the same RCM (or a different one) to produce the desired high-resolution simulation (at 10 or 20 km).

24. Two sets of projections were completed, using two of the IPCC Representative Concentration Pathways (as described above): RCP 4.5 (lower) and RCP 8.5 (higher). The ability of GCMs and RCMs to simulate the current climate (1980-2000) was validated by comparing their output with observations from 70 stations in Viet Nam and global observational or reanalysis datasets.

25. Current climate trends and variability of temperature and rainfall as well as the impacts of climate drivers such as ENSO and tropical cyclones were analyzed in detail, both annually and for monsoon-based seasons.

26. Downscaled projections of future climate for Viet Nam and the sub-regions were then produced to show Viet Nam-wide changes in temperature and rainfall. The multi‐model mean changes are reported, along with the percent agreement of the sign-of-change among the downscaled results and the spread among the model projections. These provide some measure of confidence in the projections.

27. The data generated were further analyzed to determine changes in monsoon onset date and tropical cyclone frequency. Extreme indices such as 1-day and 5-day rainfall and the heat wave duration index were computed to indicate possible changes in drought duration and frequency.

F. Sea Level Rise

28. Updated sea-level rise projections for the oceans surrounding Viet Nam were developed using information from the latest global models, with added understanding of other contributing factors such as glacial melting and changes in land-based water resources. For SLR, all four Representative Concentration Pathways (RCP 2.6, 4.5, 6.0 and 8.5) were considered. Sea level data up to 2014 were used in combination with digital topographic maps updated to 2016.

29. Sea level rise (SLR) inundation maps were based on the average sea level rise due to climate change. SLR scenarios considered average sea level change as affected by thermal expansion of the oceans, glacier melt, dynamics of the polar ice sheets, changes of water reserves on continents, and isostatic adjustments of ice sheets.

30. However, other dynamical factors such as tectonic uplift and subsidence, topographical changes, land subsidence due to groundwater extraction, coastline change, influence of tides, storm surges, monsoon induced sea level rise, impact of hydropower cascade, and saline intrusion were not considered in these scenarios. Also, transportation works and irrigation structures, sea dykes and river dykes, embankments, roads, and others were not considered in the mapping of inundation.

ANNEX B: BASELINE AND PROJECTED CLIMATE IN BIIG-2 PROVINCES

1. These baseline and climate change projections for the north-central region of Viet Nam, which covers the four BIIG2 provinces, are taken from MONRE's *Climate Change and Sea Level Rise Scenarios for Viet Nam*, published in 2016. Supplemental information was taken from the INHEM's *High-Resolution Climate Projections for Viet Nam's North-Central Region*, published in 2015 and used to support the updating of Viet Nam's official climate change and sea-level rise scenarios.[23]

A. Baseline

2. Annual temperature observations showed a significant trend of about 0.11 to 0.24°C increase per decade, while annual rainfall observations showed some changes. In general, the number of hot days (days with temperatures above 35°C) has increased in most regions of the country. Number of droughts increased over the country, especially severe droughts.

3. Current climate features:

- Annual average temperature: 23 to 25°C
- Maximum temperature: 40 to 42.7°C
- Minimum temperature: 3 to 8°C
- Annual average rainfall: 1500 to 2000mm
- Daily maximum rainfall: 150 to 500mm
- Rainfall season: Aug to Dec

4. A trend analysis based upon available data within the last 50 years (1961–2010) showed that:

- *Annual temperature has increased*: Annual temperature in this region has increased significantly by approximately 0.11 to 0.24°C per decade. Only at the Hue station has the temperature decreased slightly.
- *Minimum temperature has increased more than maximum temperature*: While minimum daily temperature has increased significantly by up to approximately 0.28°C per decade, the trend in maximum daily temperature is smaller, especially in the northern parts of the region.
- *More hot days and fewer cold nights*: The number of hot days (T above 35°C) has increased significantly at some stations by up to 7 days per decade. The number of cold nights (T below 15°C) has decreased at some stations by up to 2 days per decade.
- *Annual rainfall has some changes*: Most of the station observations showed almost no change or slight decreases in annual rainfall, although in the southern-most part (at Aluoi) there are significant increases of up to approximately 11% per decade.
- *Extreme rainfall amounts have not changed*: Annual maxima of 1-day and 5-day rainfall amounts and the number of very wet days have not changed significantly for most stations in this region.

B. Temperature change projections

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[23] Regional summaries of climate change were developed as part of the *High-resolution Climate Projections for Viet Nam Project* funded by Australia's Agency for International Development.

5. Surface air temperatures, annual and seasonal temperatures (winter, spring, summer, autumn), show increasing trends for the northeast region compared to the reference period (1986-2005). In general, temperature change in the northern regions of Viet Nam is projected to be higher than in the South.

6. Under Scenario RCP 4.5, the mean value of projections from various models on the increase in average temperature for the 4 BIIG 2 provinces is 0.6°C by early 21st century (80% likelihood of the actual value falling between 0.3°C to 1.2°C). By mid-century, it is projected the increase in average temperature across the 4 provinces would be 1.5°C (80% likelihood of being in the range 1.0°C to 2.2°C).[24]

7. Under Scenario RCP 8.5, the mean model prediction on increase in average temperature in the 4 provinces is 0.9°C, with 80% likelihood of falling in the range 0.6°C to 1.5°C. By mid-century, it is projected that the change in average temperature would be 1.9°C, with 80% likelihood of falling in the range 1.3°C to 3.1°C.[25]

Table 8. Projected Change in Average Temperature

Province	RCP 4.5			RCP 8.5		
	2016-2035	2046-2065	2080-2099	2016-2035	2046-2065	2080-2099
Nghe An	0.7 (0.3 to 1.1)	1.6 (1.1 to 2.2)	2.2 (1.5 to 3.1)	1.0 (0.6 to 1.5)	2.0 (1.4 to 3.1)	3.7 (2.9 to 5.2)
Ha Tinh	0.6 (0.3 to 1.0)	1.5 (1.0 to 2.1)	2.0 (1.4 to 2.9)	0.9 (0.6 to 1.3)	1.9 (1.3 to 2.8)	3.5 (2.8 to 4.8)
Quang Binh	0.6 (0.3 to 1.1)	1.5 (1.0 to 2.1)	2.0 (1.5 to 2.8)	0.9 (0.6 to 1.2)	1.9 (1.3 to 2.8)	3.3 (2.7 to 4.7)
Quang Tri	0.6 (0.4 to 1.2)	1.4 (1.0 to 2.0)	1.9 (1.3 to 2.8)	0.9 (0.6 to 1.2)	1.9 (1.3 to 2.7)	3.3 (2.6 to 4.6)

8. Extreme temperatures are projected to increase in all climate zones. By late 21st century, for the RCP4.5 scenario, average annual maximum temperature is projected to increase by 1.7°C to 2.7°C (80% probability). Under this scenario, the average annual minimum temperature would also increase by 1.8 to 2.2°C (80% probability). For the RCP8.5 scenario, the average annual maximum temperature would increase by 3.0°C to 4.8°C, with the highest increase in the northern mountainous provinces.

9. The average annual minimum temperature would increase by 3.0 to 4.0°C, with higher rates associated with the Northern provinces. The number of extreme cold days is projected to decrease in the Northern mountainous provinces, the Red River Delta, and the North Central provinces.

C. Rainfall

10. Annual rainfall and extreme rainfall intensities are projected to increase in all climate zones.

11. Under Scenario RCP 4.5, the average value (over the 4 provinces) of modeling projections on the increase in annual rainfall by early 21st century is 10.7% compared to the reference period or baseline (1986-2005), i.e., with 80% likelihood of being in the range 2.4% to 20%. By mid-

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[24] The range of the indicated temperature change refers to the 10% and 90% percentile values of the projections from the 16 model runs, hence representing 80% likelihood that the actual value falls in that range.

[25] A statement like “change ranging from 1.6°C to 3.2°C” means that if the upper and lower range limits correspond, respectively, to the 10th and 90th percentile values derived from the modeling simulations, then it is inferred that there is an 80% probability or likelihood that the actual value is between 1.6°C to 3.2°C. The value placed in front of the range represents the average of the simulation results.

century, it is projected that the average increase in annual rainfall over the 4 provinces would be 15.6% compared to the reference period.

12. Under Scenario RCP 8.5, the mean of the model predictions for the increase in annual rainfall over the 4 BIIG 2 provinces is 14.2%, i.e., compared to the reference period. By mid-century, it is projected that the change in annual rainfall would be 16.6% compared to baseline.

Table 9. Projected Change in Annual Rainfall (with reference to 1986-2005)

Province	RCP 4.5			RCP 8.5		
	2016-2035	2046-2065	2080-2099	2016-2035	2046-2065	2080-2099
Nghe An	10.2 (2.4 to 17.7)	16.8 (10.6 to 23.1)	18.1 (10.3 to 26.3)	16.6 (7.7 to 24.5)	21.6 (14.1 to 28.5)	26.4 (18.8 to 33.6)
Ha Tinh	11.3 (6.0 to 16.6)	16.3 (8.5 to 24.4)	13.0 (3.4 to 22.6)	12.9 (6.8 to 18.9)	14.1 (8.9 to 19.0)	17.4 (10.6 to 24.4)
Quang Binh	10.1 (3.5 to 16.5)	12.6 (3.8 to 22.0)	10.9 (0.0 to 21.4)	10.8 (4.0 to 17.4)	14.1 (8.2 to 19.6)	12.1 (5.5 to 19.0)
Quang Tri	11.4 (2.9 to 20.0)	16.6 (7.5 to 26.2)	20.1 (9.8 to 31.3)	16.5 (9.9 to 22.8)	16.8 (10.7 to 22.6)	16.4 (8.2 to 24.2)

D. Sea Level Rise

13. Sea level rise scenarios only consider changes in average sea water level caused by climate change. The scenarios do not take in to account the effects of other factors on sea water level, such as storm surge, monsoon induced water level rise, tide, tectonic uplift and land subsidence.

14. By early 21st century, there is no significant difference in sea level rise for all RCP scenarios. By 2030, the average sea level rise for Viet Nam coast would be about 13 cm (8 to 18 cm) under both RCP 4.5 and RCP 8.5.

15. By mid-21st century, there is a difference in trend of sea level rise. By 2050, average sea level rise for the coastal areas of Viet Nam are about 22 cm (14 to 32 cm) for the RCP 4.5 scenario, and about 25 cm (17 to 35 cm) for the RCP 8.5 scenario.

16. By late 21st century, differences in trend of sea level rise for different RCP scenarios are clear. By 2100, average sea level rise for the coastal areas of Viet Nam would be about 53 cm (32 to 76 cm) for the RCP 4.5 scenario, and about 73 cm (49 to 103 cm) for the RCP 8.5 scenario. Data for Viet Nam is summarized in Table 10.

Table 10. Sea Level Rise scenarios averaged for coastal areas of Viet Nam (cm)

Scenarios	Timeline			
	2030	2050	2080	2100
RCP 2.6	13 (8 to 19)	21 (13 to 32)	35 (21 to 52)	44 (27 to 66)
RCP 4.5	13 (8 to 18)	22 (14 to 32)	40 (24 to 57)	53 (32 to 76)
RCP 6.0	13 (8 to 17)	22 (14 to 32)	41 (27 to 58)	56 (37 to 81)
RCP 8.5	13 (9 to 18)	25 (17 to 35)	51 (34 to 72)	73 (49 to 103)

17. The coastal BIIG2 provinces are covered by two sea level monitoring regions as shown in Table 11.

Table 11. BIIG 2 Sea Level Rise projections (cm)

	Coastal region	2030	2050	2080	2100
RCP 4.5	Hon Dau-Đeo Ngang	13(8 to 18)	22(13 to 31)	39(24 to 56)	53(32 to 75)
	Đeo Ngang-Đeo Hai Van	13 (8 to 18)	22(14 to 32)	40(24 to 56)	53(32 to 75)
RCP 8.5	Hon Dau-Đeo Ngang	13 (9 to 18)	25(17 to 35)	50(34 to 71)	72(49 to 101)
	Đeo Ngang-Đeo Hai Van	13(9 to 18)	25(17 to 35)	50(34 to 71)	72(49 to 102)

Note: In this Table, the levels of confidence were set at 5% and 95%.

E. Storm Surge

18. Storm surge is a rise in sea level due to the direct impact of a typhoon. Although the frequency is not high, storm surges can be very dangerous due to sudden water level rise causing inundation for the coastal areas. Storm surge characteristics are different for different areas of the coastal areas of Viet Nam.

Table 12. Storm Surge Heights (cm)

Coastal area	Observed highest storm surge (cm)	Highest storm surge that can occur (cm)
Quang Ninh - Thanh Hoa	350	400
Nghe An – Ha Tinh	**400**	**450**
Quang Binh - Thua Thien - Hue	**300**	**350**
Đa Nang - Binh Đinh	150	200
Phu Yen - Khanh Hoa	150	200
Ninh Thuan - Binh Thuan	150	200
Binh Thuan - Ca Mau	200	250

Note: BIIG-2 provinces lie along the Nghe An to Hue coastline.

19. Typhoon surges may cause serious damages to sea dykes and coastal constructions, and are especially dangerous if they occur during high tides. In areas with high tidal amplitudes, even a relatively small storm surge can cause flooding if it were to happen during high tide.

20. MoNRE has estimated that the total sea water level caused by a storm surge happening in combination with high tide of 200-year return period along the coastline of Quang Ninh to Nghe An could reach 500 cm. The extent of inundation associated with various levels of SLR, as estimated by MoNRE, is shown below for the BIIG 2 provinces.

Table 13. Extent of Inundation due to Sea Level Rise

Province	Province Area (ha)	Percent of area to be inundated corresponding to SLRs (cm)					
		50	60	70	80	90	100
Nghe An	1,656,000	0.13	0.17	0.22	0.27	0.32	0.51
Ha Tinh	599,304	0.86	1.00	1.2	1.39	1.81	2.12
Quang Binh	801,200	1.73	1.87	2.01	2.24	2.27	2.64
Quang Tri	463,500	0.71	0.97	1.22	1.49	1.91	2.61

ANNEX C: CRVA FRAMEWORK AND METHOD

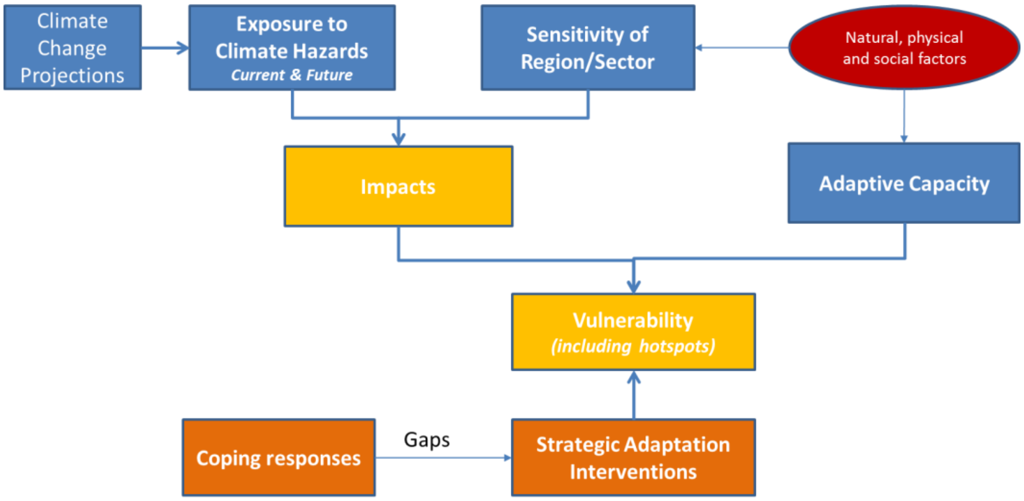
A. Framework

1. Vulnerability is defined as the degree to which a *system* is susceptible to the adverse effects of change. In the climate context, change is manifested by increasing weather variability and a projected long-term shift in climate patterns, particularly for extreme weather events.

2. Vulnerability is a function of the nature, magnitude, and speed of climate change to which an area or sector is exposed, as well as its sensitivity and its adaptive capacity. Specifically, exposure is defined as "the nature and degree to which a system is exposed to significant climatic variations"; sensitivity is defined as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli"; and adaptive capacity is defined as "the ability of a system to adjust to climate change (including climate variability and extremes), to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences".

3. Exposure to climate hazards is influenced mainly by geographical location. Sensitivity and adaptive capacity, on the other hand, are context-dependent. Adaptive capacity are non-climate factors that either aggravate or mitigate the effects of climate change. The latter depends on access to resources and support systems, management capacity, and in the case of BIIG2 the design standards for infrastructure planning.

Framework for Climate Change and Vulnerability Assessment



4. Following this framework, information is collected on climate change exposure derived from regional climate modeling data, sensitivity of affected areas, and adaptive capacity.

- *Exposure* captures the level of potential exposure to extreme climate-related events (drought, storm surge, landslides, flooding and sea-level rise) and predicted change to baseline climate parameters (temperature and precipitation), by combining future climate model data with information on past (extreme) events.

- *Sensitivity* measures the sensitivity of the system of interest—in this case, infrastructure--to climate change hazards because of location, nature of the infrastructure (e.g., bridges that are sensitive to flood levels) and so on.

- *Adaptive Capacity* measures the ability or potential of managing entities to adjust to anticipated stresses resulting from climatic change. This includes various non-climate factors like watershed condition and management, engineering design parameters, etc.

B. Method and steps

- Identify context of vulnerability to climate change
- Assess vulnerability to *current* climate hazards (climate variability and extreme weather events)
- Based on long-term climate change projections, assess how the magnitude and frequency of hazards may change in coming decades (do not rely on just one model or one set of predictions)
- Examine probable impacts on infrastructure elements
- Identify adaptation strategy/options
- Formulate specific measures and prepare an implementation plan

C. During feasibility studies

5. *Scoping*: Identify the climate parameters to which subprojects are vulnerable (e.g., precipitation, temperature, extreme weather events). Focus the information collection on the relevant parameters. Different types of subprojects may involve different sets of climate change parameters (e.g., if the water source is river, groundwater, reservoir) and site (coastal, upland).

6. *Impact assessment*: Understand how the climate parameters may affect the subprojects (e.g., precipitation's effect on dependable water, supply, extreme rain events on structural integrity, etc.). Combine with understanding the role of other factors, e.g., watershed conditions, topography, population density.

7. *Vulnerability assessment and strategic resilience measures*: Understand how the climate parameters are expected to change under climate change scenarios as predicted for Viet Nam (using whatever climate projection databases are "approved" by MoNRE's hydromet department). Then examine the impact of those changes on the structural viability, operational performance (especially on their maintenance and periodic rehabilitation requirements), and longevity/sustainability of the subprojects. Identify strategies/measures for adaptation.

D. During detailed engineering design

8. *Adaptation planning*: What specific measures, provisions and planning considerations are warranted to address the assessed vulnerable aspects of the subprojects (e.g., design parameters, materials and construction methods, maintenance scheme). Assess how/when these measures can be applied: immediately at the time of implementation? not immediately, but build the project so that retrofits can be made as and when necessitated? not at all? what other strategies are acceptable to decision makers and stakeholders?

9. *Implementation arrangements*: How will the adaptation measures be implemented, who are responsible, and how will the measures be financed? Arrangements will vary depending on

the nature of the measures (engineering vs non-engineering) as well as on the degree of coordination and funding required. Financing considerations are important, especially on how to tap climate change adaptation support funds.

10. *Monitoring and feedback*: Very important because adaptation is a site-specific and iterative process of adjustment/learning, given also the inherent uncertainty in the severity and timing of climate change impacts. As lessons are gained, these can be fed back to the policymakers and mainstreamed into sector policy and planning.

E. Some issues and challenges

11. A central issue is understanding, communicating and handling uncertainty—using the term "uncertainty" as understood in science, rather than in the commonly mistaken sense of not being sure or lacking information with which to act.

12. There is scientific consensus that climate change will alter the hydrologic cycle in important ways (water is the entry point). But despite continuing advances in climate change science, uncertainty about impacts and outcomes remain. The difficulty is that the science community and its terminology uses terms like "risk", "likelihood" and "uncertainty" that policy makers and the public, including even engineers, mistake for lack of information needed to act, encouraging either skepticism or a wait-and-see attitude.

13. But planners and decision makers cannot wait for climate change uncertainty to somehow be cleared up by science or more evidence before acting, for such uncertainty is unavoidable and will not disappear. Rather, there is a need to fundamentally change the planning and decision-making strategies by taking on an adaptive approach to development, one that confronts uncertainty directly and proactively manages its implications. The old planning paradigm which shuns uncertainty is no longer appropriate. Climate change resilience is fundamentally about managing uncertainty. Water resource management decisions must pay attention to present-day risks of increasing climate variability and extreme weather, and be robust to the uncertainties of future climate change.

14. The sequencing of weather events as simulated in models, e.g., occurrences of the El Nino Southern Oscillation, will not correspond to observations, since the models are not constrained to reproduce the timing of the natural climate variations. Users of climate change data should thus bear in mind that projections derived from models, no matter how sophisticated, are not to be regarded as predictions of actual future climate. Rather, such projections provide simulations of future climate under a variety of hypothetical development and GHG emissions scenarios, and (recently through the RCPs) also alternative global policy choices.

15. Climate projections are driven by assumptions in any case, and should be interpreted properly and with caution considering the unavoidable uncertainty. The occurrence of any discrete climate change event cannot be pinpointed exactly, except through use of probabilities or likelihood estimates. And it is not possible to precisely predict the size and form of climate change impacts, particularly at the local level where water adaptation measures must be implemented.

16. Since uncertainty in climate change management is unavoidable, the aim is to minimize it. This is done, for example, by choosing climate models that capture well the dominant climate feature of a region and, preferably, by not relying on just one model. The other aim is to quantify uncertainty so that the range of probable outcomes can be expressed probabilistically, to be

useful for planning and decision making (by producing a range of projections, an ensemble of models enables statistical analysis to be applied).

F. Two-step adaptation planning

17. A two-step procedure for risk-based infrastructure planning is usually followed, and which also serves as basis for justifying supplemental adaptation funding, e.g., from climate funds.

18. To quantify and assess the risk/uncertainty implications of climate change on water resources planning, a two-step planning procedure may be followed:

- In the *first* step, a baseline planning scenario is established; this is defined as 'business-as-usual' water resources development with no consideration of the likely implications of long-term climate change. It uses data derived from historical records.
- In the *second* step, an alternative scenario is defined as the basis for planning. The alternative scenario(s) is based on climate change projections and it includes outcomes that are to be achieved by a set of adaptation measures that *explicitly* address climate change risk. In short, this is an altered plan that includes measures for climate resilience.

19. This two-step procedure enables decision-makers to better assess the risk posed by climate change on water development plans, and to quantify the cost implications of providing measures for climate adaptation/resilience. However, it is not yet routinely done in water planning unless the projects in question are being co-financed by climate funds that mandate such two-step procedure (so that the basis for justifying the cost of adaptation is easier to assess).

20. Developing an alternative project planning scenario incorporating climate change projections requires using climate modeling data, for instance, to examine climate change hazard exposure. This two-step logic applies more readily in the case of climate-proofing types infrastructure. For instance, one can assess the design difference and estimate the cost implications between that of upgrading infrastructure to meet current service standards (which serves as the baseline scenario), versus that of upgrading it to higher standards to anticipate climate change effects.

21. The benefit measurement of an adaptation measure that addresses a climate change scenario in development planning derives from the damages avoided with reference to a baseline. In practice, such avoided damages are difficult to estimate given the uncertainty inherent in the modeling tools for climate change prediction. Occurrences of any discrete climate change event cannot be pinpointed, except through use of probabilities. And as only the frequency and severity of events over time can be projected, damages can only be estimated in a probabilistic sense. Nonetheless, this framework enables decision-makers to systematically account for risk and to assess the robustness of the plan.