PHUENTSHOLING TOWNSHIP DEVELOPMENT PROJECT

DISASTER AND CLIMATE RISK AND VULNERABILITY ASSESSMENT

MAY 2018

ABBREVIATIONS

ADB	-	Asian Development Bank
AEP	-	Annual Exceedance Probability
ALDTP	-	Amochhu Land Development and Township Project
CC	-	Climate Change
CDCL	-	Construction Development Corporation Limited
DCRVA	-	Disaster and Climate Risk and Vulnerability Assessment
DOR	-	Department of Roads
DHI	-	Druk Holdings and Investment Limited
EA	-	Executing Agency
EIA	-	Environment impact assessment
IA	-	Implementing Agency
IDPR	-	Integrated Detailed Project Report
MAP	-	Mean Annual Precipitation
NECS	-	National Environment Commission Secretariat
PPTA	-	project preparatory technical assistance
PTDP	-	Phuentsholing Township Development Project

WEIGHTS AND MEASURES

ha	–	Hectare
km	–	kilometer
MCM	–	million cubic meters
mm	–	millimeter
m^3	–	cubic meter

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I. OVERVIEW

A. Introduction

1. This appendix records the Disaster and Climate Risk and Vulnerability Assessment (DCRVA) undertaken for the Phuentsholing Township Development Project (PTDP). Key geophysical hazards include earthquakes and landslides. Key climate change risks include (i) increased frequency and intensity of flood events, and (ii) increased frequency and intensity of precipitation events leading to increased frequency of landslides. The disaster risk management aspects of the project are mainly focused on water-induced disasters, namely floods.

2. The city of Phuentsholing is in a geographically and commercially strategic position on the Bhutan-Indian border and, after the capital Thimphu, is the second largest city in Bhutan. Phuentsholing is located adjacent to the Amochhu River, which, emerging from its steep upstream reaches onto the plains, broadens to a width exceeding 1km. Figure 1 shows the general location, in an oblique aerial image looking north-east (upstream). The confluence of the Amochhu and Omchhu is shown, as is Jaigaon, the city to the south, which is in India.

Figure 1: 3D Google Earth image of Phuentsholing and Amochhu

Source: HCP.[1] Main report. Fig 2.53

3. The Amochhu river system has its origin in China and flows through the western Bhutan districts of Ha and Samtse before finally draining via Chhukha district onto the plains of India. The upper catchment is at a high elevation with steep slopes. Its source is Mount Pauhunri (7,128 metres (m) above mean sea level [AMSL]) on the border with India and China. The catchment area down to Phuentsholing is approximately 3,785 square kilometres (km^2).[2] The

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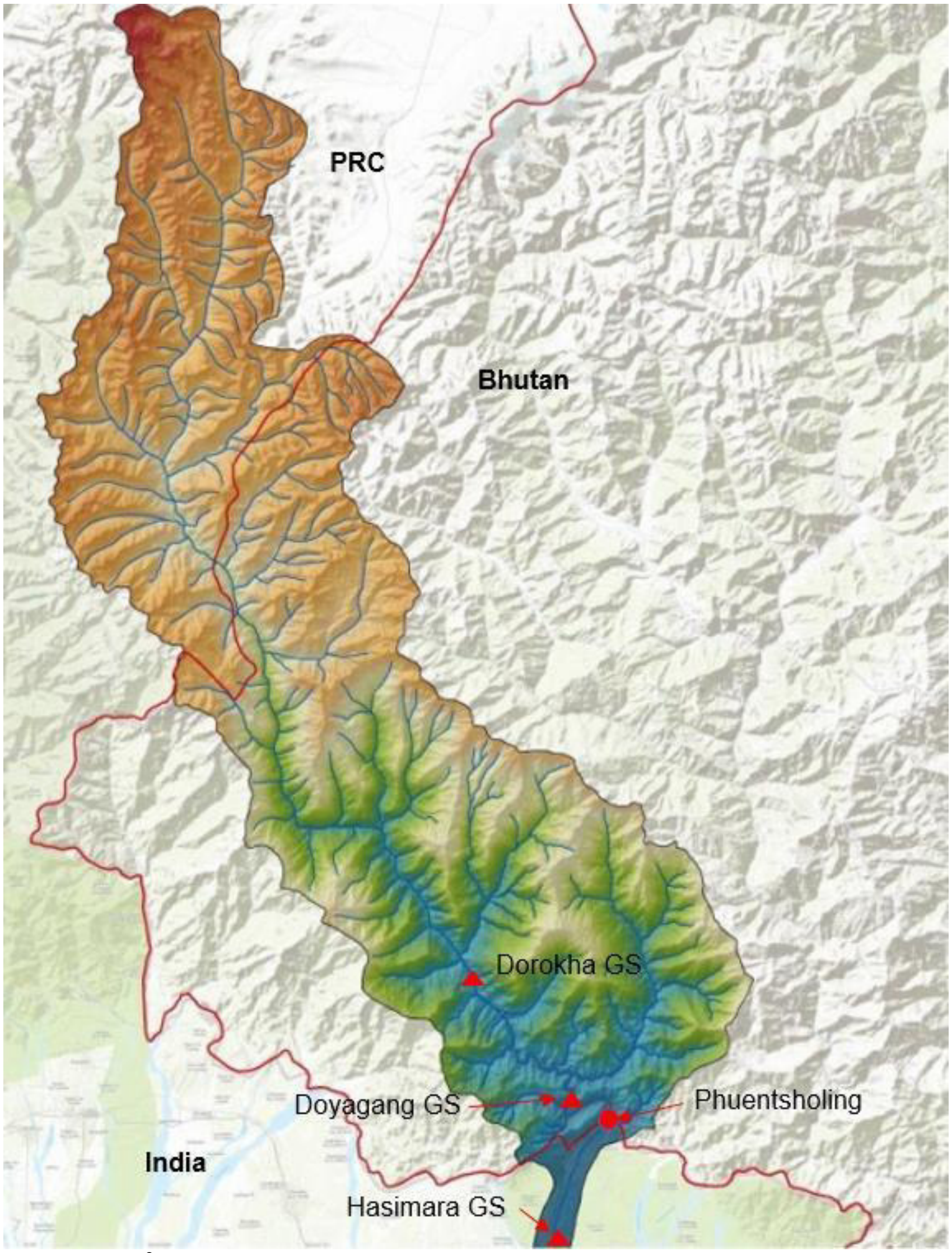
[1] HCP, *Stage 3: Integrated Detailed Project Report (IDPR) – 2nd Draft*, 12 August 2016.

[2] Estimates vary from 3700-3900km^2. This value is from DHI India, *Toorsa River Flood Mitigation Project – Detailed Feasibility Study and Engineering Design – Data Collection Report*, prepared by DHI Water & Environment (DHI India), January 2007.

catchment area down to Hasimara gauging station in India, 15 kilometres (km) downstream of the Indo-Bhutan border, is 4,006 km^2. Figure 2 shows the catchment area and locations of interest.

Figure 2: Amochhu catchment area



Source: HCP.[3]

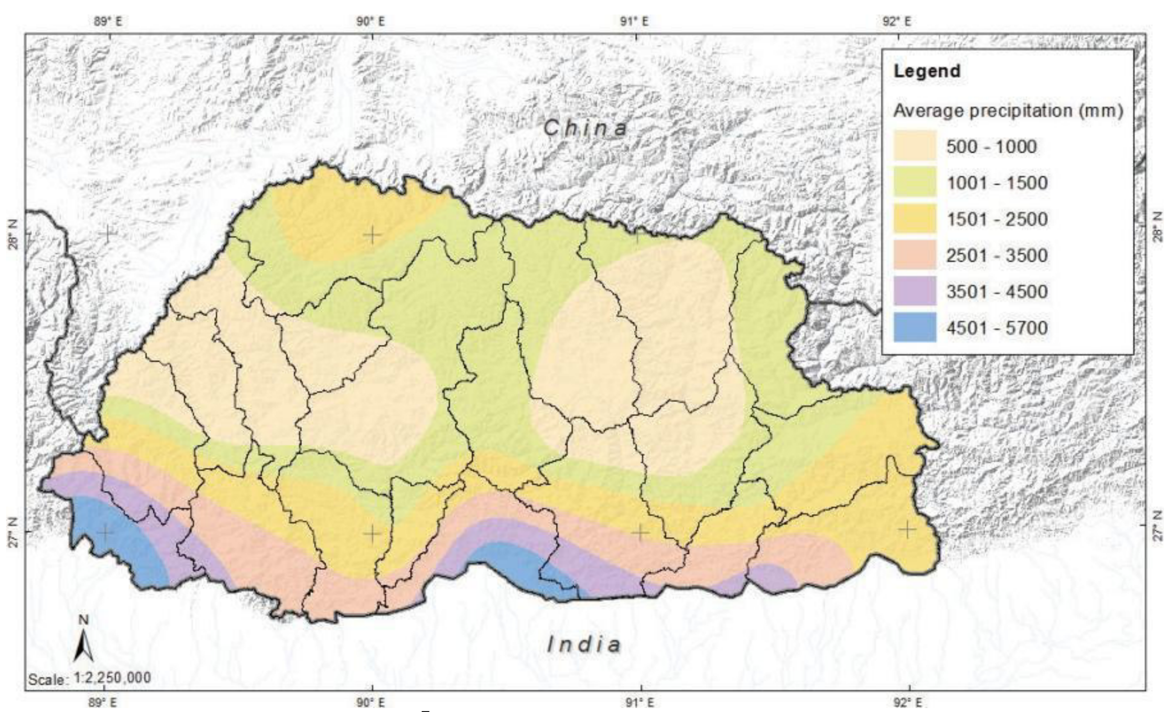
[3] HCP, *Stage 3: Integrated Detailed Project Report (IDPR) – 2nd Draft*, 12 August 2016. Annex 4. Fig 2.1. Annotated by PPTA. Boundaries are not necessarily authoritative.

4. Permanent snow cover measured from the satellite images is 348 km^2, with all of that in China.[4] The net rain fed area up to Hasimara is 3,658 km^2 (91%). The upper catchment adjoining the Chinese border has a nature reserve covering 650 km^2. Downstream to Phuentsholing the catchment is forested. At Phuentsholing, the vegetation within the catchment is of two types, namely northern dry mixed deciduous and Lower Chil pine.

5. The climate is subtropical and humid in the southern plains and foothills. Phuentsholing is at a relatively low altitude of 220 m AMSL, corresponding to the plain areas of India. Meteorological stations at Jalpaiguri[5] and Hasimara[6] both have a mean annual temperature of approximately 24 ºC. Temperature data is sparse in the catchment upstream in Bhutan, however the variability can be expected to be high. High altitudes of 4,880 m AMSL, and more in areas bordering China and within China, are in the permanent snow zone and experience sub-zero temperatures throughout the year.

6. Rainfall in the catchment ranges from 4,500 millimetres (mm) per annum at Phuentsholing, to arid conditions in the permanent snow covered areas in the uppermost part of the catchment. Sombekha at 1,760 m AMSL is the highest gauge in the catchment. Mean annual precipitation declines further up the catchment, approaching desert conditions in the high Himalayas in China. Figure 3 shows annual precipitation for Bhutan, demonstrating the trend.

Figure 3: Precipitation map of Bhutan (isohyets)



Source: Department of Agriculture[7]

7. The monsoon season generally lasts from June to September with shoulder months in May and October. Monsoons characteristically give rise to highly intense rainfall in the lower

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[4] DHI India. 2007. *Toorsa River Flood Mitigation Project – Detailed Feasibility Study and Engineering Design, Draft Final Report*, Delhi. Prepared by DHI Water, Environment and Health (DHI India).

[5] 75km south-west. Elevation 90 mASL.

[6] 15km due south. Elevation 120 mASL.

[7] Department of Agriculture, *National Irrigation Master Plan*, Ministry of Agriculture and Forests, 2016.

catchment above Phuentsholing, decreasing with distance upstream. As a result, the river is flashy, with flood waves passing in a matter of hours. Observed flood stage and discharge data at Hasimara has been recorded since 1978. The maximum observed discharge of 5,397 cubic metres per second (m^3/s) was recorded on 13 July 1996. It had a total duration of about 50 hours.

8. The Himalayan Mountains are geologically young and active, and prone to landslides. The high velocity of flow induced by the steep slopes results in a high sediment load including sand, gravels, cobbles and boulders, leading to an unstable bed, and bank erosion. At Phuentsholing, the river widens from 100 m to 1,200 m, with a high degree of morphological activity in the river bed and on the banks.

9. Documented evidence of fluvial flood damage in Phuentsholing prior to 2015 is scarce.[8, 9] The flood information typically available in written reports, such as the maximum observed water level (e.g. flood wrack marks) and erosion damage sustained in riparian areas, is unavailable. Anecdotally, floods resulting in significant damage have been experienced in 1993, July 1996, August 2000,[10] May 2009,[11] July 2015,[12] and July 2016. Figure 4 shows examples of flood damage during and following the 2015 event.

10. Owing to increasing population and limited area, the city is facing a serious shortage of land for development and expansion. Sedimentation and erosion resulting directly from uncontrolled river flows has been a major contributor to the loss of valuable flat land along the western limit of the city of Phuentsholing. The high monsoon flows have eroded vast areas of land, restricting the scope for growth and sustainability of the economy of the city.

11. Past attempts to protect the river banks have achieved limited success, mainly owing to a piecemeal approach to river training. A holistic approach to protecting the banks is necessary, with the additional benefit of reclaimed land.

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[8] Fluvial flooding refers to floods derived from rainfall and/or snowmelt. In this case, the snowmelt contribution would be minor.

[9] The 2015 event was documented by DHI Infra in *Assessment Report on Flood at Amochhu Land Reclamation & Township Project site on July 1, 2015*, report prepared by DHI-Infra Ltd (now CDCL), July 2015.

[10] Resulted in widespread damage in Phuentsholing, Pasakha and other southern cities. In Phuentsholing it resulted in deep scouring of the river banks and destruction of the in-river water supply intake structure. There was significant flooding of Phuentsholing due to the Omchhu at the same time, which eventually resulted in construction of a flood defence scheme for this major tributary, funded by the ADB.

[11] This was during Cyclone Aila.

[12] Estimated peak discharge was 2,340 m^3/s.

Figure 4: July 2015 flood inundation and lateral erosion damage

Source: DHI-Infra Ltd[13]

12. In addition to the climate-related hazards, there are geophysical hazards including earthquakes and landslides. The Department of Disaster Management summarises the geophysical hazard setting for the country in a 2006 publication. Not all hazards covered in the publication are applicable to the Amochhu and Phuentsholing. For example, Glacial Lake Outburst Floods (GLOF) are not a feature due to the absence of glacier lakes in the catchment, however a summary regarding earthquakes and landslides is applicable as follows:[14]

[13] DHI Infra in *Assessment Report on Flood at Amochhu Land Reclamation & Township Project site on July 1, 2015*, report prepared by DHI-Infra Ltd (now CDCL), July 2015

[14] Ministry of Home & Cultural Affairs, *National Disaster Risk Management Framework*, report prepared by Department of Local Governance, Ministry of Home & Cultural Affairs, Royal Government of Bhutan, 2006. http://www.ddm.gov.bt/download/DRMF_Final.pdf, Accessed 21/5/17

(i) Earthquakes[15]. *Bhutan lies in one of the most seismically active zones of the world. Although a detailed and comprehensive seismic zone map of Bhutan is unavailable, its proximity to the north-eastern parts of India, which is in the 'most active' seismic Zone V (according to Bureau of Indian Standards), indicates that the majority of Bhutan is either in Zone IV or V. Despite the high risk of earthquakes occurring in the region, there is little by way of 'official' historical records tracking earthquakes and consolidating the relevant data. Records suggest that while four great earthquakes of magnitude exceeding 8 on the Richter scale occurred during 1897, 1905, 1934 and 1950, another 10 earthquakes exceeding magnitude 7.5 have occurred in the Himalayan belt during the past 100 years. In recent years, Thimphu, Paro and Phuentsholing have witnessed the effects of three significant earthquakes. The earthquake of 1980 (6.1 on Richter scale), with its epicenter in Sikkim (India), caused several cracks in buildings in Thimphu, Phuentsholing, Gelephu, Samdrup Jongkhar and Trashigang. There were also reports of some damages caused to houses in the villages. Also, in its aftermath, the Phuentsholing – Thimphu national highway was blocked by landslides caused by the tremor. The earthquakes of 1988 (6.6 on Richter scale) and 2003 (5.5 on Richter scale) with epicenters in the Indo-Nepal border and Bhutan respectively, also caused similar damages to human settlements, institutional buildings (including schools, hospitals, Dzongs etc.) and highways.*

(ii) Landslides. *Landslide events are closely linked with flooding events, and are also recurrent phenomena in Bhutan. Slopes in the country are highly susceptible to landslides especially in the rainy season. Most occur in the eastern and southern foothill belt where the terrain is steep and rocks underlying the soil cover are highly fractured, allowing easy seepage of water. Contributing factors are the undercutting of slopes by high-energy rivers and streams during a period of heavy rainfall. Landslides can also be caused by the tremors of an earthquake, as witnessed in the aftermath of the 1980, 1988, and 2003 earthquakes. The urban areas experience secondary effects of landslides due to the importance of road infrastructure for the dispatch of vital goods. Farmers on steep slopes and foothills of the south and the eastern region of the country are regularly affected by the hazard.*

(iii) Natural dam formations and dam bursts (landslide dams[16]). *Due to Bhutan's steep terrain, narrow river gorges, unstable physical structures, and increasing incidences of landslides during monsoon have led to the incidences of artificial dam and lake formation on the rivers. In September 2003, there was a dam formation due to rock slide on the Tsatichhu, a tributary of Kurichu. An estimated volume of 33 million* m^3 *was impounded. In May 2004, the dam began to fail leading to dam burst on 10 July 2004 causing downstream environmental impacts. The Kurichu Hydropower Corporation authorities, however, managed to open the reservoir gates in time to avoid major destruction to the dam and other casualties. Such hazards will continue to prevail in Bhutan's rivers placing many of the hydropower plants, farmlands, human settlements, social infrastructures and numerous properties of cultural, social and historical significance that are located along the country's large rivers valleys.*

[15] In addition to the earthquakes listed in this 2006 publication, there was the 6.1 magnitude earthquake in Mongar to the east of Thimphu on 21/09/09 which killed 12 people, and the 6.9 magnitude earthquake in Sikkim to the west of Bhutan on 18/09/11.

[16] There is no evidence of landslide dam break flooding in the Amochhu.

13. The Global Risk Data Platform[17] has been interrogated to access data for Phuentsholing and the adjacent areas. Findings include:

- Past earthquake events in Phuentsholing with a magnitude of 5.8-6.6, consistent with the DDM summary.
- Physical exposure to landslides triggered by precipitation ranges from 300-1,000 people/year to more than 1,000 people/year in Phuentsholing.[18]
- Hazard due to landslides triggered by precipitation is rated as High, on a scale between Low and Very High.
- Physical exposure to landslides triggered by earthquakes ranges from 30-100 people/year to more than 1,000 people/year in Phuentsholing.
- Hazard due to landslides triggered by earthquakes is rated as High, on a scale between Low and Very High.
- Landslide mortality risk is rated as High, on a scale between Low and Extreme.

B. Project

14. The government seek to ultimately develop about 462 hectares (ha) of riparian land near the city of Phuentsholing along both sides of the Amochhu River under a long-term development plan called "Amochhu Land Development and Township Project" (ALDTP). The project will provide protection from floods and erosion, and construct smart urban infrastructure to allow phased urban expansion. The project will also protect the existing town from floods and riverbank erosion which currently threatens lives and livelihoods and disrupts connectivity with nearby communities.

15. The ultimate development of ALDTP is divided into five Zones: A to E. Zone D represents Kaileshwar Hill and is not included in the project for development. The remaining four zones comprising development on Amochhu riparian land will require about 15 km of riverbank protection with new common urban infrastructure (roads, water supply, waste water management, municipal solid waste management, power and telecommunications) to support habitation for up to 50,000 people. The allocation of land and riverbank protection for the project's four development zones is summarized in Table 1 and shown in Figure 5:

Table 1: Summary of Project Components

Zones	Area (ha)	Riverbank Protection Length (m)
A	66	3,974
B	94	3,046
C	277	4,872
E	27	3,083
Total	**462**	**14,975**

[17] Global Risk Data Platform, supported by UNEP and UNISDR, is a multiple agency effort to share spatial data information on global risk from natural hazards. http://preview.grid.unep.ch, accessed 22 May 2017.

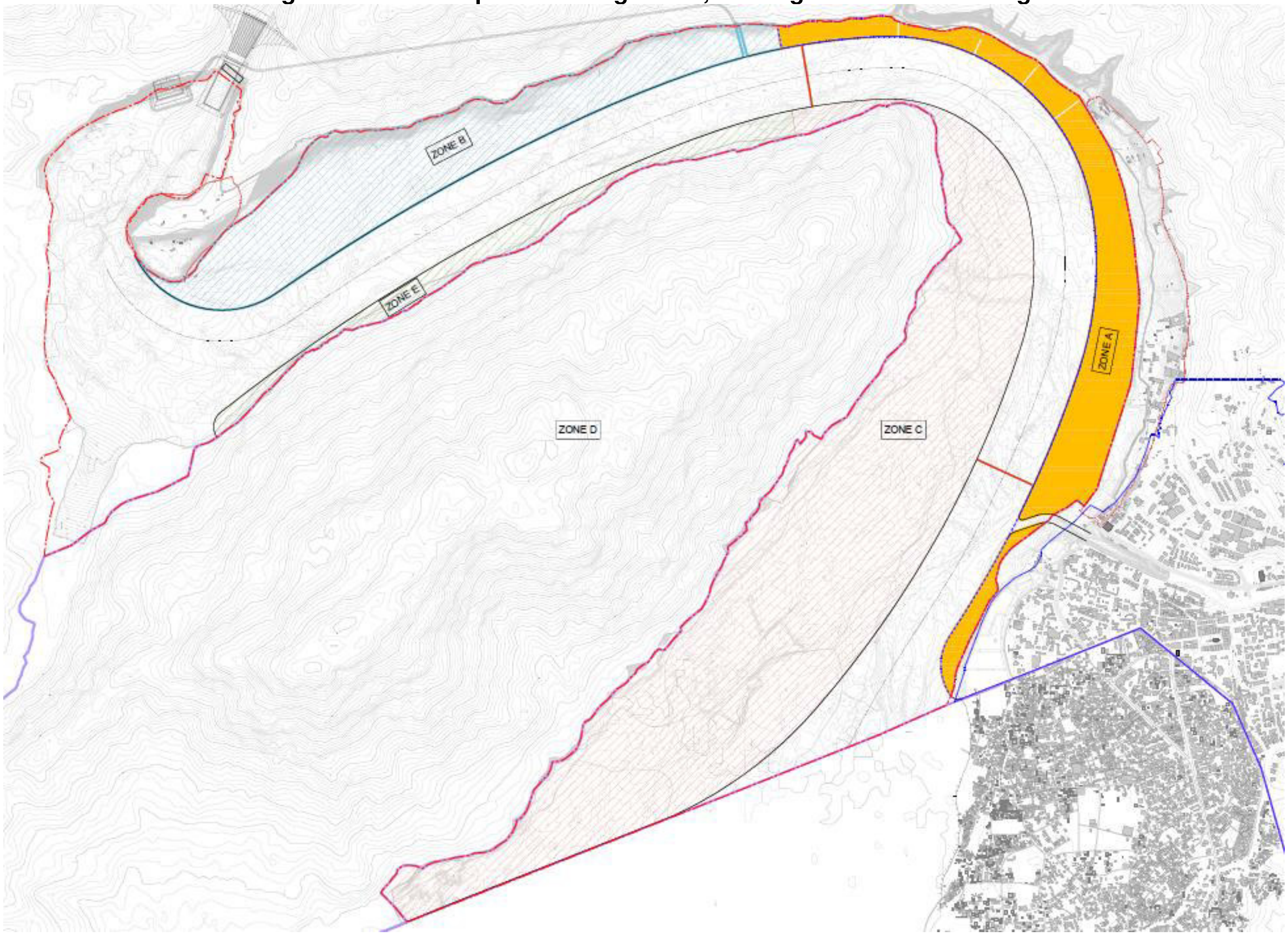
[18] This dataset includes an estimate of the annual physical exposition of landslide triggered by precipitations. It depends on the combination of trigger and susceptibility defined by six parameters: slope factor, lithological (or geological) conditions, soil moisture condition, vegetation cover, precipitation and seismic conditions. A population grid for the year 2010, provided by LandScanTM Global Population Database (Oak Ridge, TN: Oak Ridge National Laboratory). Unit is expected average annual population (2010 as the year of reference) exposed (inhabitants). This product was designed by International Centre for Geohazards /NGI for the Global Assessment Report on Risk Reduction (GAR). It was modeled using global data and aggregated to ~ 5 km resolution for distribution. Credit: GIS processing International Centre for Geohazards /NGI.

Source: PPTA Consultant

16. Implementation of the project will be phased in relation to the scale and demand for the development. PTDP comprises the first phase will develop Zone A while subsequent phases will develop the remaining zones.

17. The PTDP investment will comprise packages for civil works, goods, and consulting services for the 66 hectare Zone A. It will also integrate urban infrastructure services with a local planning area (LAP) of the existing town.

Figure 5: Location plan showing zones, training wall extent and alignment



Source: HCP drawing BM-PB-01.

II. CLIMATE RISK SCREENING

18. The project climate risk screening is informed by the climate change study report produced for the SASEC project[19] and an AWARE risk assessment for the PTDP. The SASEC climate change study report is presented in Annex 1 and the AWARE assessment in Annex 2.

19. Climate change findings for the SASEC project are predominantly based on a study by Singh[20] that projected trends in mean annual and seasonal (monsoon/wet and winter/dry) temperature of approximately 3.5 ^{0}C and 3 ^{0}C respectively over the period 1980 to 2069. It also projects an increase of up to 30% (600 mm/year) in annual precipitation over the same period. It also projected seasonal differences with an increase in monsoonal mean total precipitation up to 34% (approximately 450 mm/year) over the same period.

20. The SASEC project assessed the road project's exposure and possible impacts of climate change considering the vulnerability of the project.[21] They concluded that "*The Amochhu is a potential risk during the monsoon and since the project is located at the base of the mountains, it receives a lot of discharge from the catchments. There is a risk of flooding, submergence, landslides and siltation of the drainage structures and road infrastructure in general. Any increase in rainfall intensity, duration and frequency will cause higher peak flows resulting in flooding and landslides. The following climate change induced risks are identified: (i) damages to road infrastructure due to flooding and landslides; (ii) reduced road safety due to flooding and landslides; (iii) disruption of road connectivity and services; and (iv) increased road maintenance costs*."

21. The climate change induced risks identified for the SASEC project are applicable to Zone A, as the proposed road forms the eastern and northern boundary of Zone A. They are also applicable to the other zones.

22. Additional risk analysis was also prepared using the AWARE project assessment (Annex 2). The AWARE assessment evaluates risks within sixteen individual topic categories and provides an overall final project risk. The individual risks are presented on a radar chart within three colour bands; green band (inner circle) suggests a lower level of risk in relation to a risk topic, red band (outer band) suggests a higher level of risk and orange band (middle band).

23. Table 2 presents a summary of the risk topic for the overall project. The project is rated as high risk and therefore warrants further assessment of potential impacts.

Table 2: Summary Risk Assessment

Risk Topic	**Project**
A) Temperature increase	
B) Wild fire	
C) Permafrost	
D) Sea ice	

[19] ADB. 2016a. *Initial Environmental Examination, BHU: SASEC Transport, Trade Facilitation and Logistics Project*. Prepared by Department of Roads for ADB, Project Number: 47284-002, May 2016.

[20] Singh B. 2011. *Vulnerability and Adaptation Assessment, Volume 1: Technical Paper*. Prepared for National Environment Commission, Royal Government of Bhutan, Second National Communication from Bhutan to the United Nations Framework Convention on Climate Change, September 2011.

[21] ADB. 2016b. *Final Report, Volume I – Main Text, TA 8708 (BHU): SASEC Transport, Trade Facilitation and Logistics Project.* Prepared by Egis International for ADB, July 2016.

Risk Topic	Project
E) Precipitation increase	
F) Flood	
G) Snow loading	
H) Landslide	
I) Precipitation decrease	
J) Water availability	
K) Wind speed increase	
L) Onshore Category 1 storms	
M) Offshore Category 1 storms	
N) Wind speed decrease	
O) Sea level rise	
P) Solar radiation change	

Source: PPTA Consultant adapted[22] from AWARE analysis

24. The key risk topics include floods and landslides (both rated high), and precipitation increase. The most relevant to the specific PTDP project activities and infrastructure include:

- **Precipitation increase:** may result in an increase in flood frequency and intensity, and therefore impact on river and drainage infrastructure
- **Flood**: increased frequency and intensity of flood events may increase erosion and siltation of water courses, landslide events, surface flooding (pluvial) and damage to drainage systems.
- **Landslide**: an increase in landslide activity may increase sediment generation and debris flows, leading to conveyance issues for cross drainage facilities.

III. ASSESSING ADAPTATION NEEDS AND OPTIONS

25. The adaptation measures appropriate to the project are derived in a three-step process namely: impact, vulnerability and adaptation analysis.

26. Impact assessments are typically “top-down”, drawing from largely global and regional climate change models to project future climate changes at the local level. The vulnerability assessment also takes into consideration observed current vulnerability and climate patterns, or a “bottom-up” assessment, for example trends based on information collected by meteorological stations and experienced by local communities. Both types of assessments have a certain amount of uncertainty but together provide the best available knowledge, which can provide insights into decision making for adaptation.

27. Based on the above, an assessment of the various adaptation options (ideally including those already in practice) is made from expert opinion and stakeholder consultations. This is carried out on both engineering and non-engineering solutions. The options are then weighed against each other through a cost-benefit/cost-effectiveness analysis to help identify the most effective adaptation measures.

28. Consideration of the likelihood of climate change impacts based on current conditions and future trends are used to assess the most appropriate design and adaptation options. These priority adaptations will be implemented through the program and monitored through

[22] The PPTA changed snow loading from red to green as there is no snow in the lower parts of the catchment.

identified indicators. Given the uncertainties in projecting climate change, options which provide other co-benefits are likely to be lower risk.

A. Impact Assessment

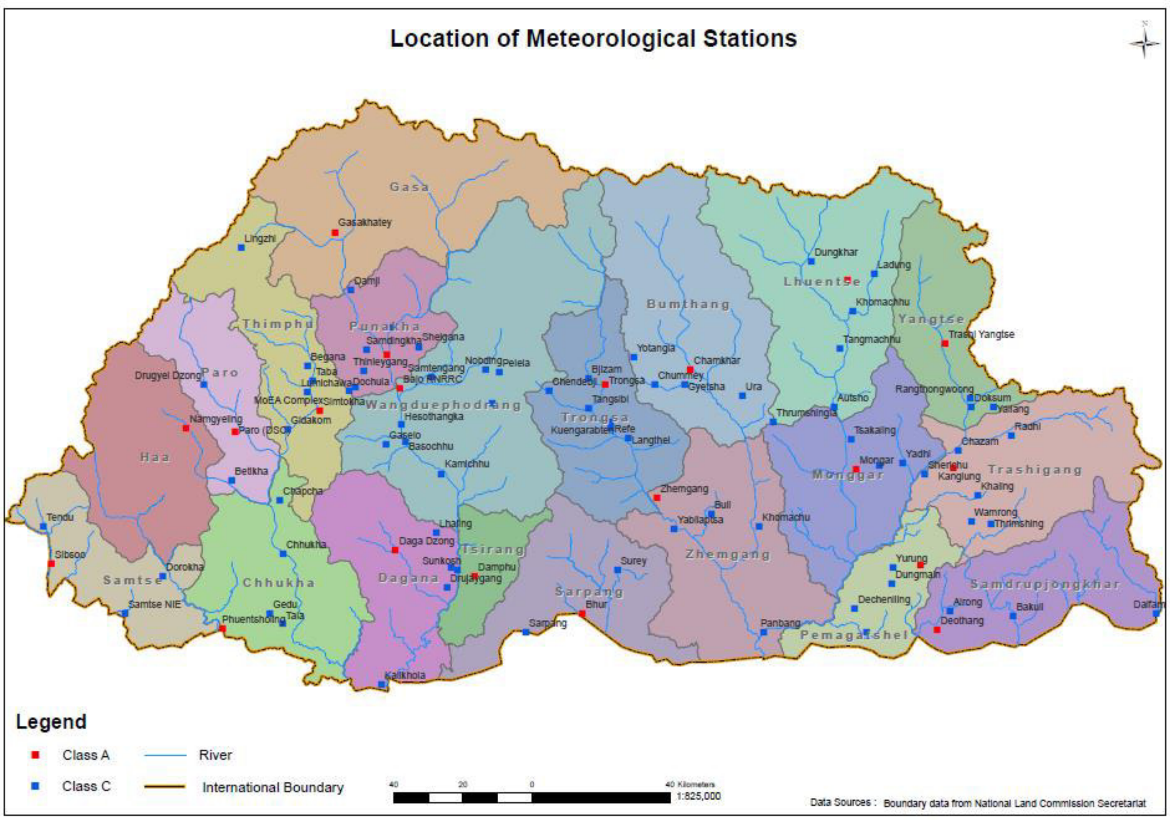
1. Recent Climate Trends

29. While there are several climate change parameters, the principal ones directly relevant to the project for the assessment of risk and adaptation measures are changes in rainfall.

30. The Department of Hydro-Met Services (DHMS) under the Ministry of Economic Affairs of Bhutan (MOEA) is the national agency in Bhutan to study and provide hydrological and meteorological services. The first meteorological observations in Bhutan were started in 1985, and the earliest hydrological measurements date back to the early 1980s.

31. DHMS operates 20 agro-meteorological stations and 76 climatology stations (Egis, 2016a). The Class A stations are agro-meteorological stations recording 8-9 climate parameters while Class C stations are climatological stations recording 3-4 parameters. Observations at most stations are conducted manually but there are 11 automatic weather stations.

Figure 6: Current Network of Meteorological Stations in Bhutan

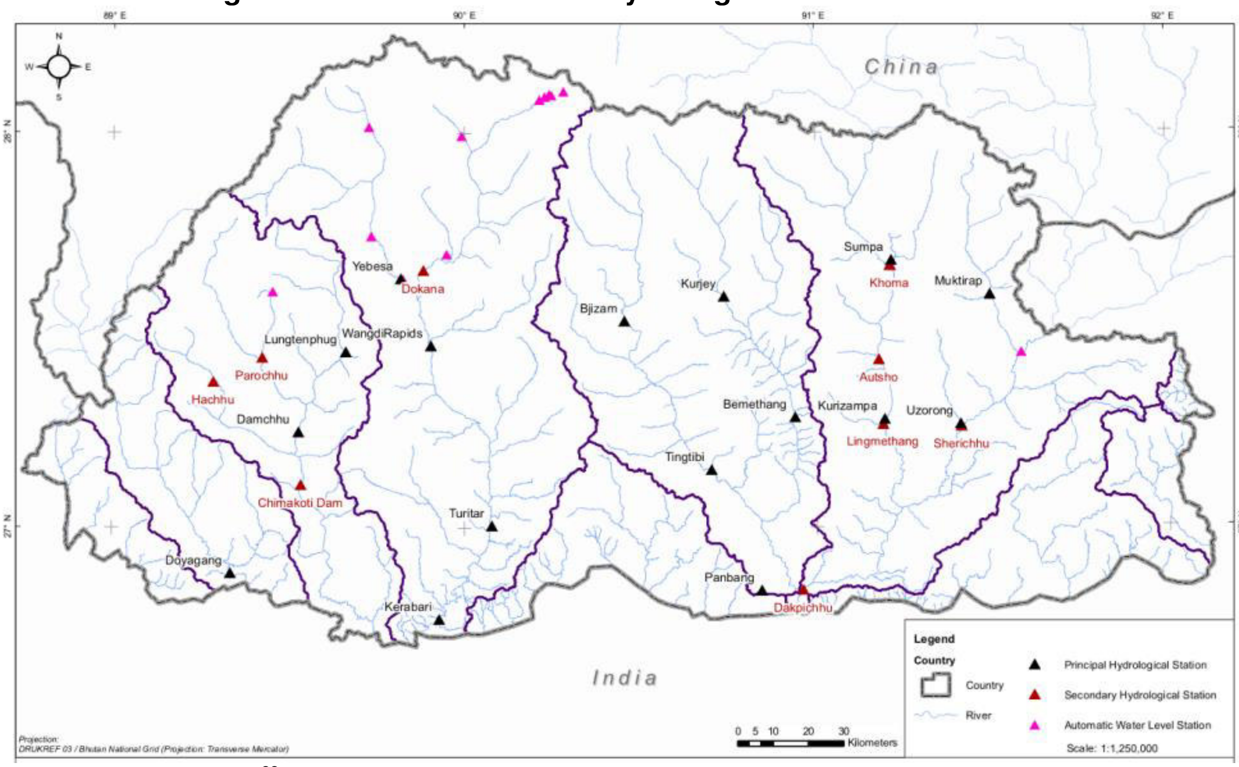


Source: Egis 2016b. Hydrological Modeling and Assessment for Bhutan, part of ADB Contract No. CDTA 8623-BHU, Adapting to Climate Change through IWRM, Egis International, April 2016. Figure 2.3.

32. DHMS operates 26 hydrological stations, 10 sediment sampling stations and 15 Flood Warning Stations, which monitor river levels (Egis, 2016a). Of the 26 hydrological stations, 16

are considered principal stations and 10 are secondary. Principal stations are equipped with staff gauges, cableway, and level gauge.

Figure 7: Current Network of Hydrological Stations in Bhutan



Source: Egis 2016c.[23] Page 42.

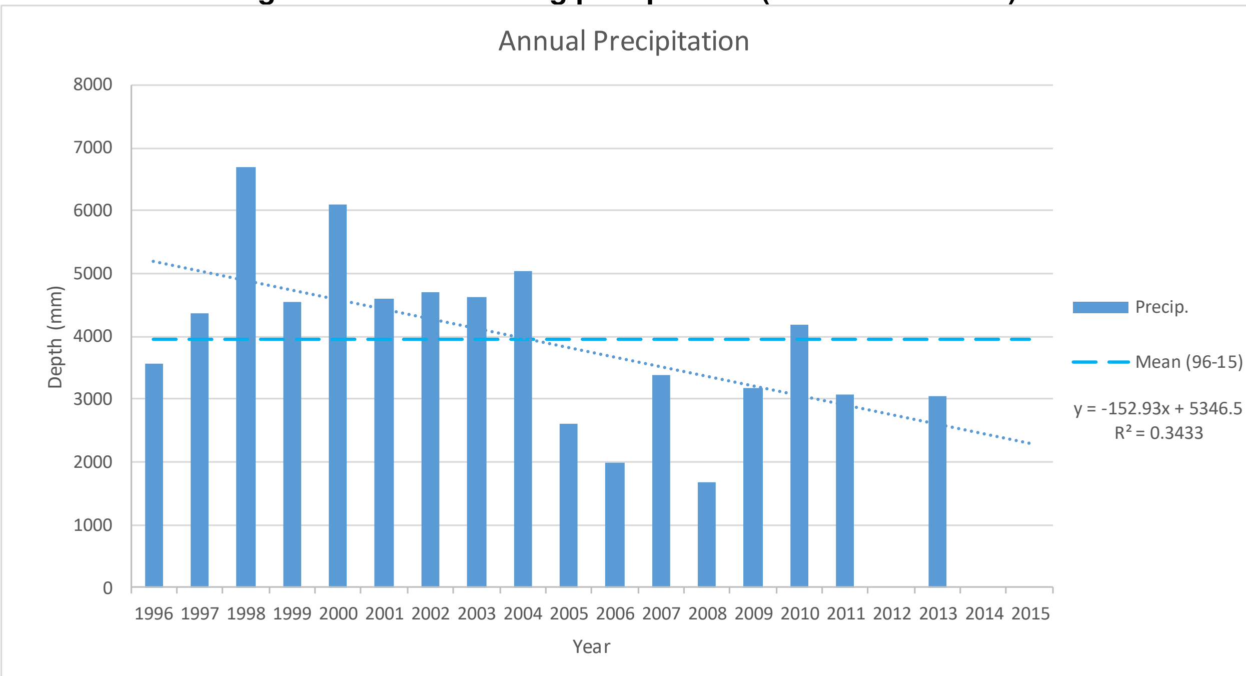
33. Rainfall data at Phuentsholing (Station 11150046) is available since 1996. The same applies to stations at Tendru (22370046), Sibsoo (22320046), and Tala (12210046). Samtse (22240046) and Gedu (12220046) data was recorded from 1990 while Dorokha (11300146) and only started in 2005.

34. In terms of the hydrological stations, Dorokha (11390049) and Doyagang (11210045), both on the Amochhu, started in 2003 and 2004 respectively. Both are known to have significant stage-discharge rating issues that diminish their data utility.

35. Figures 8 to 12 show the available recorded annual precipitation between 1996 and 2015 for Phuentsholing, Gedu, Samtse, Sibsoo and Tendru. The mean for each site is plotted, as well as a linear trend line. Gaps are shown for years when there are 30 or more missing daily values in the record during the monsoon season.

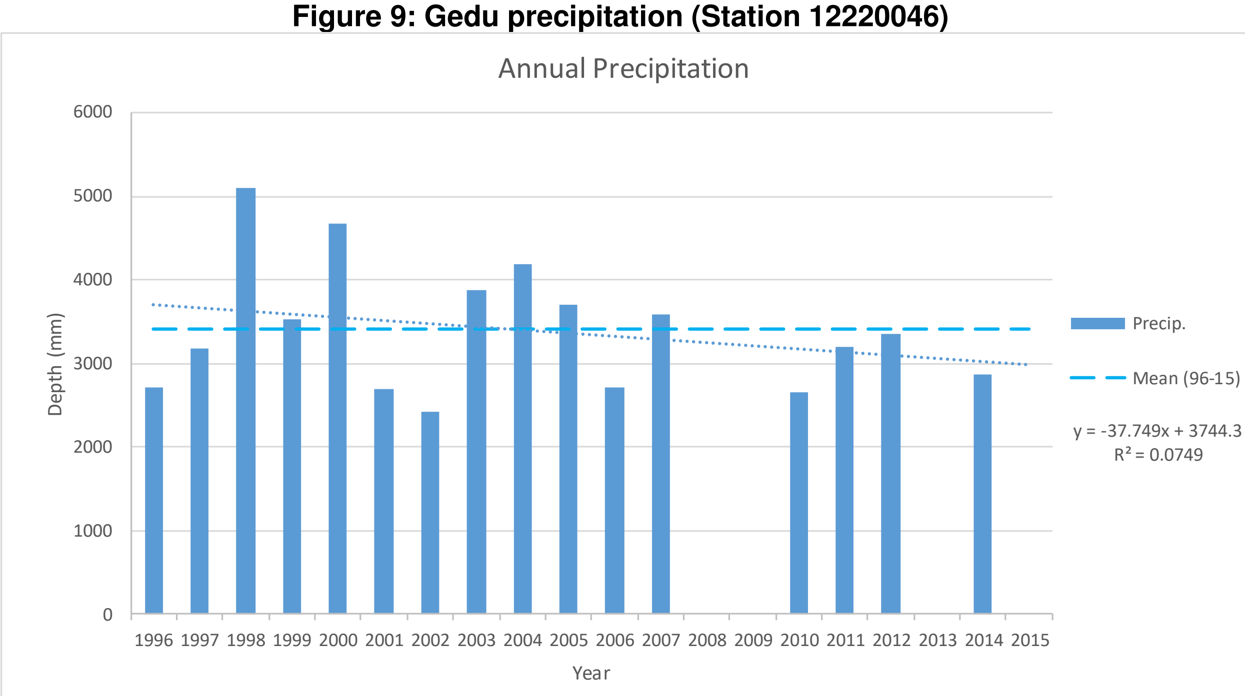
[23] Egis. 2016c. *National Atlas of River Basins and Water Infrastructure in Bhutan*, part of ADB Contract No. CDTA 8623-BHU, Adapting to Climate Change through IWRM, Egis International, March 2016

Figure 8: Phuentsholing precipitation (Station 11150046)



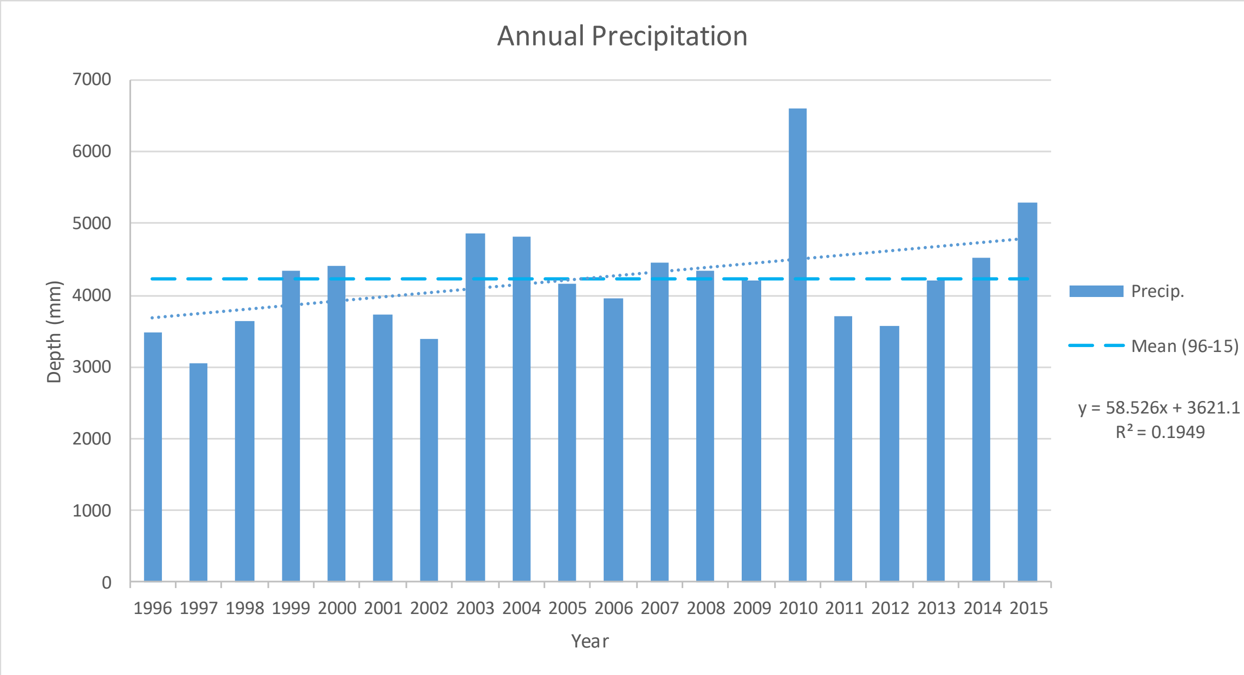
Source: PPTA, using data supplied by DHMS.

Figure 9: Gedu precipitation (Station 12220046)



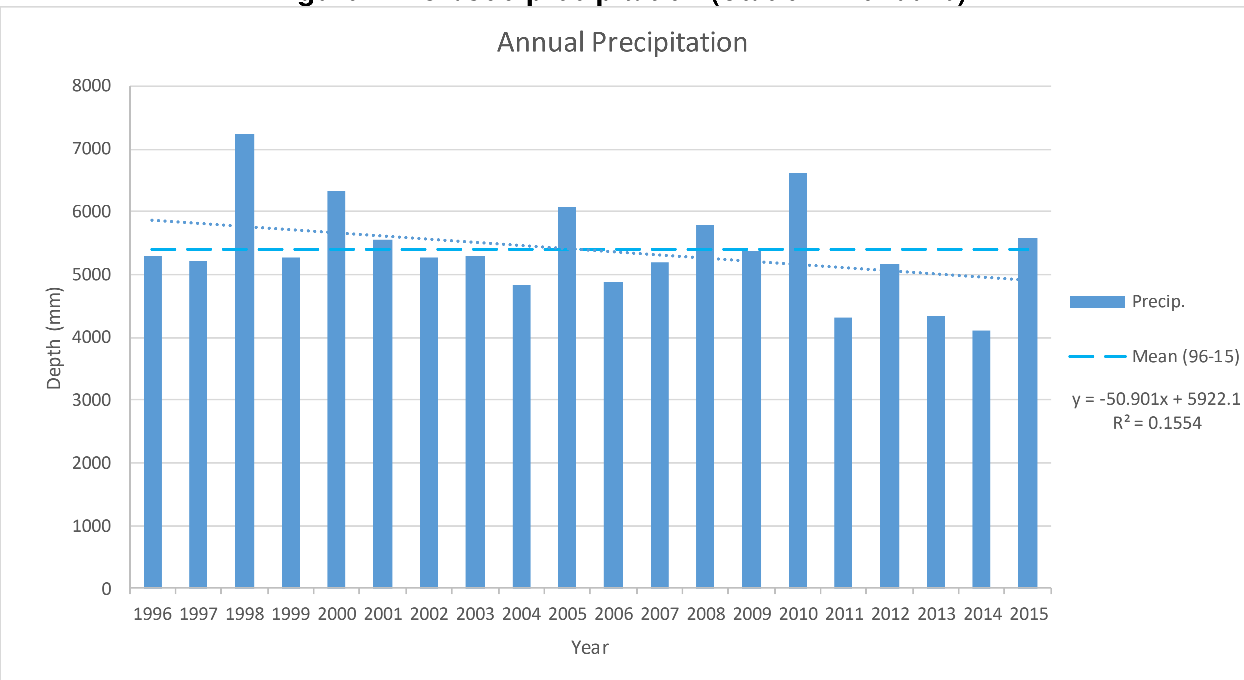
Source: PPTA, using data supplied by DHMS.

Figure 10: Samtse precipitation (Station 22240046)



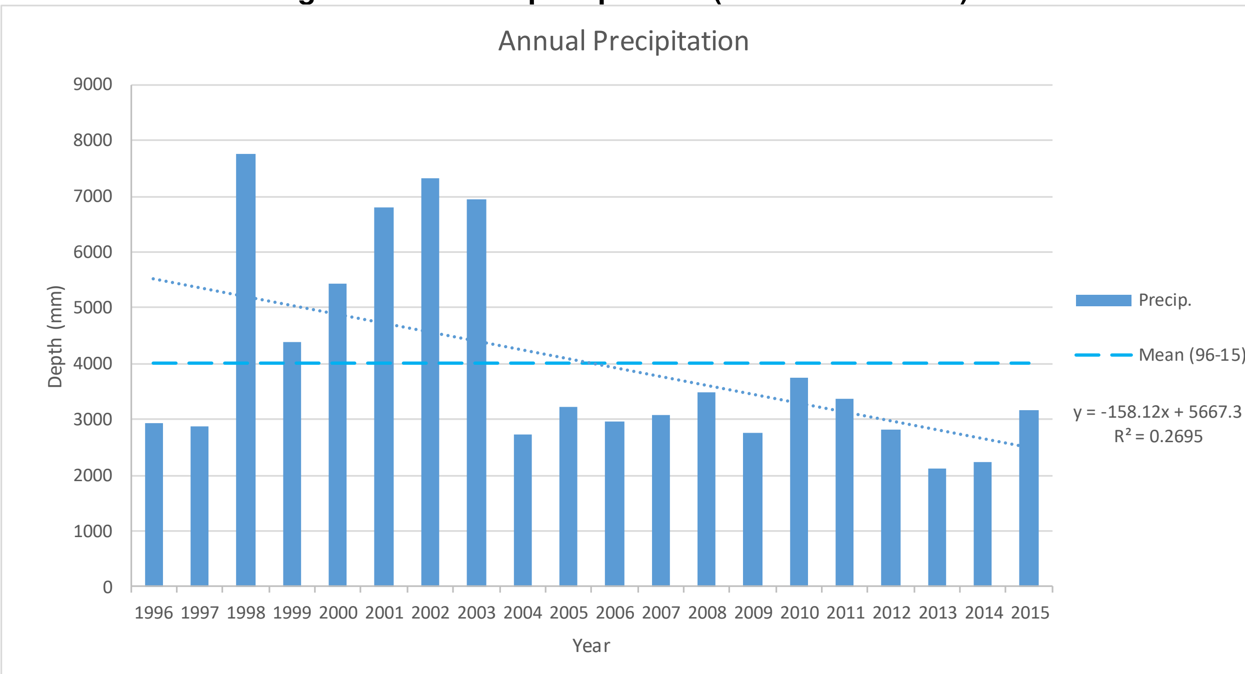
Source: PPTA, using data supplied by DHMS.

Figure 11: Sibsoo precipitation (Station 22320046)



Source: PPTA, using data supplied by DHMS.

Figure 12: Tendru precipitation (Station 22370046)



Source: PPTA, using data supplied by DHMS.

36. Phuentsholing, Gedu and Tendru all exhibit a decrease in precipitation over the period. Samtse exhibits a slight increase in precipitation over the period. No significant trend is evident for Sibsoo.

37. Similar trends were identified and reported under the ADB-financed technical assistance project “Adapting to Climate Change through Integrated Water Resources Management”.[24] This project undertaken with the National Environment Commission (NEC) and studied the likely impacts of climate change to Bhutan and how these can be managed through integrated water resources management. The outputs of the project were key government planning documents such as National IWRM Plan, Wangchhu Riverbasin Management Plan (the Wangchhu river basin neighbours the Amochhu river basin), and National Irrigation Master Plan.

38. Phuentsholing and Tendru show a noticeable change around the year 2004. If it was only one station, it would suggest further investigation is required to determine if there was a change in recording method at that time, but with a similar trend for two stations, that is unlikely to be the case. It isn’t impossible that the recording method changed at both at the same time, but a more likely reason is that both stations are subject to a similar orographic effect which is not present for the other three stations. This demonstrates the difficulty with trend analysis based on relatively short observations in hilly/mountainous regions.

39. Trend analysis of mean annual discharge at hydrological stations in the catchment would not be robust, primarily due to the stage-discharge rating issues at Dorokha and Doyagang. In summary, the quantity and quality of meteorological and hydrological data in the Amochhu catchment is insufficient to make conclusions regarding current and historical climate trends for precipitation or runoff.

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[24] NEC. 2016a. *Hydrological Modeling and Assessment for Bhutan*, part of ADB Contract No. CDTA 8623-BHU, Adapting to Climate Change through IWRM, Egis International, April 2016

2. Climate Projections

40. Climate change projections vary between sources, models and emission scenarios.

41. The SASEC climate change study[25] identified trends in mean annual and seasonal (monsoon/wet and winter/dry) temperature (^{0}C) and mean annual and seasonal (monsoon/wet and winter/dry) precipitation/rainfall (mm) for Bhutan from 1980-2069, using simulations from the downscaled HadCM3 and ECHAM5 climate models. The monsoon/wet season is assumed to last between June to September and the winter/dry season to last between December to March. The simulations consisting of dynamically down-scaled temperature and precipitation using the PRECIS regional model was carried out by NEC/START-SEA, Bangkok, Thailand. Both the HadCM3 and ECHAM5 climate models were downscaled using the SRES[26] A1B forcing scenario.[27] The downscaling using PRECIS provided climate variables diagnostics on a 22 x 22 km grid network covering Bhutan and surrounding areas.

42. The trends in Bhutan's annual mean temperature between 1980 and 2069, based on down-scaled simulations of both the HadCM3 and ECHAM5 climate models are shown in Figure 13 as yearly data and polynomially smoothed data. Both the downscaled HadCM3 and ECHAM5 climate model outputs of air temperature show a progressive and steady increase in air temperature from 1980 to 2069. However, there is a difference of approximately 1.5 ^{0}C, between the downscaled HadCM3 and ECHAM5 simulations, the HadCM3 simulations being higher. This difference was attributed to the way the two models vary certain parameters such as corrections for elevation, Bhutan being largely a mountainous country. The HadCM3 simulations therefore shows a steady increase of temperature, increasing from 13.5 ^{0}C (1980) to 17.0 ^{0}C (2069), a temperature increase of 3.5^{0}C. On the other hand, the ECHAM5 simulations show a steady increase of temperature, increasing from 12.0 ^{0} C (1980) to 15.5 ^{0}C (2069), a similar temperature increase of 3.5 ^{0}C. The seasonal (monsoonal) trend in mean temperature between 1980 and 2069 show progressive and steady increase, by 3 ^{0}C by HadCM3 simulation (19.5 ^{0}C to 22.5 ^{0}C) and about the same by ECHAM5 simulation (17.5 ^{0}C to 20.5 ^{0}C).

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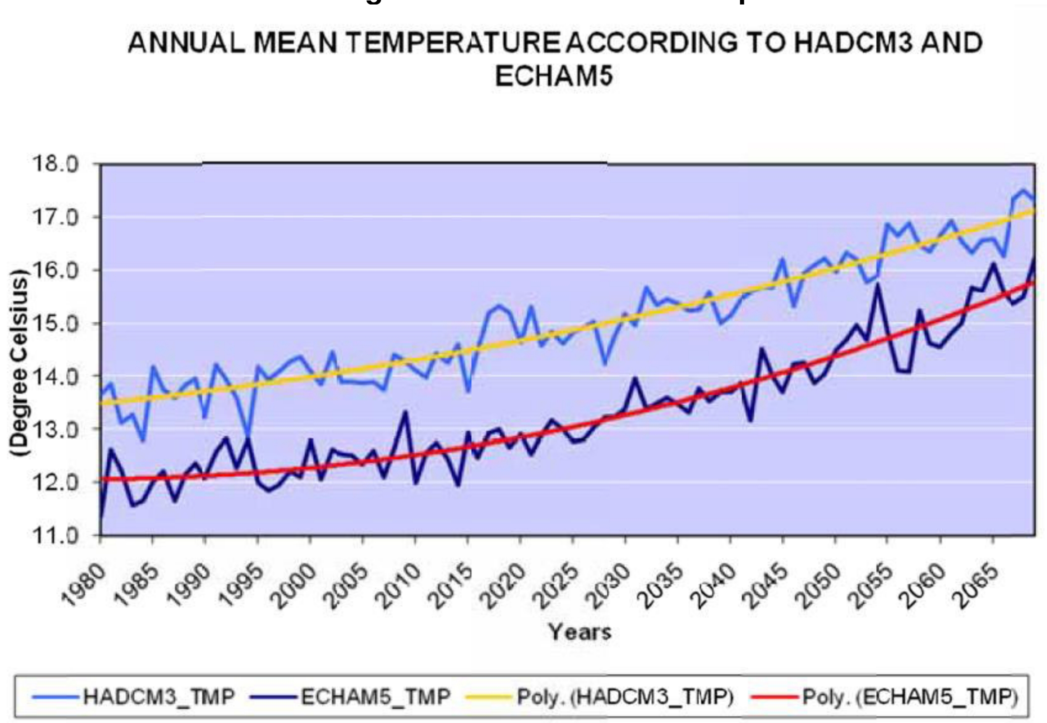
[25] ADB. 2016a. *Initial Environmental Examination, BHU: SASEC Transport, Trade Facilitation and Logistics Project*. Prepared by Department of Roads for ADB, Project Number: 47284-002, May 2016

[26] SRES refers to the *Special Report on Emission Scenarios* published by Intergovernmental Panel on Climate Change in 2000. The SRES includes several future scenarios of forcing agents (e.g. greenhouse gases and aerosols) for use as input to climate models. The scenarios do not include additional climate initiatives.

[27] *The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies)*. Source: https://www.ipcc.ch/ipccreports/tar/wg1/029.htm, accessed 26/2/17.

Figure 13: Annual Mean Temperature



Source: Singh[28]

43. The trends in annual mean total precipitation between 1980 and 2069, based on down-scaled simulations of both HadCM3 and ECHAM5 climate models are shown in Figure 14. Both the downscaled HadCM3 and ECHAM5 climate model outputs of precipitation/rainfall show a progressive and steady increase in precipitation from 1980 to 2069. However, there is a difference of approximately 100 mm/year between the downscaled HadCM3 and ECHAM5 simulations, the ECHAM5 simulations showing higher, especially towards 2069. The ECHAM5 simulations show a steady increase of precipitation/rainfall increasing from 2,000 mm/year (1980) to 2,600 mm/year (2069). The HadCM3 simulations also show increasing trend from 1,900 mm/year (1980) to 2,400 mm/year (2069).

44. The trend in monsoonal mean total precipitation between 1980 and 2069 shows progressive and steady increase. The HadCM3 simulation projects an overall increase of 350 mm/year during this period (from 1,150 mm/year in 1980 to 1,500 mm/year in 2069) and the ECHAM5 projections show an overall increase of 450 mm/year for the same period (from 1,300 mm/year in 1980 to 1,750 mm/year in 2069).

45. Similar trends for both temperature and precipitation were identified and reported under NEC climate change technical assistance (see para 35).[29] Different global climate models were used (MRI-CGCM3 and CCSSM4) with different scenarios, however the general conclusion is similar.[30]

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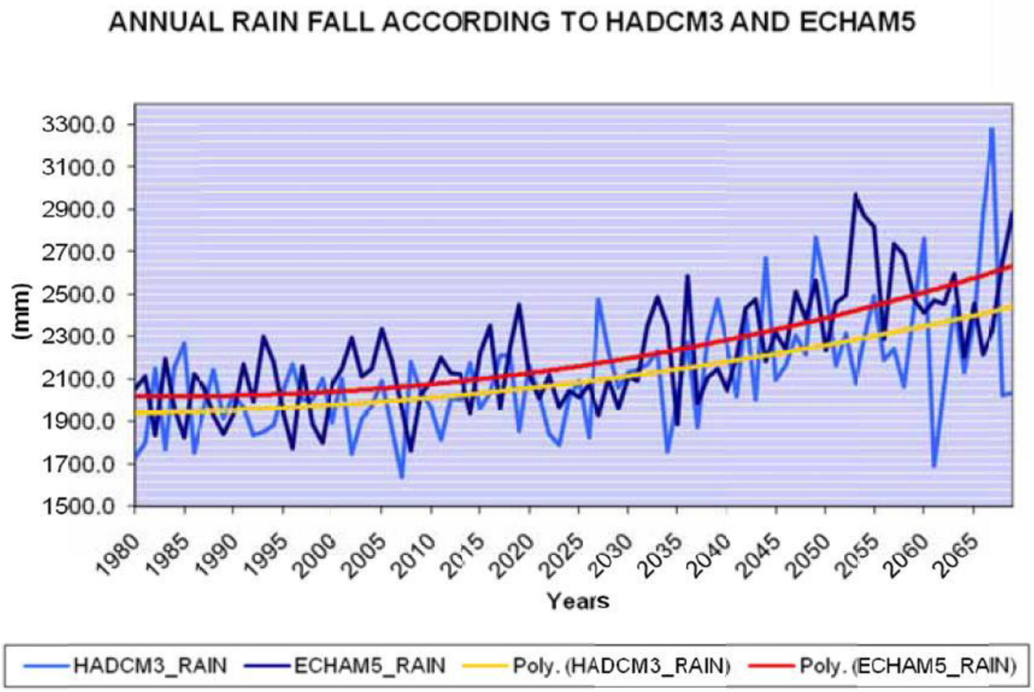
[28] Singh B. 2011. *Vulnerability and Adaptation Assessment, Volume 1: Technical Paper*. Prepared for National Environment Commission, Royal Government of Bhutan, Second National Communication from Bhutan to the United Nations Framework Convention on Climate Change, September 2011

[29] Egis. 2016e. *Climate Change Modelling and Assessment for Bhutan*, part of ADB Contract No. CDTA 8623-BHU, Adapting to Climate Change through IWRM, Egis International, April 2016.

[30] Representative Concentration Pathways (RCP) scenarios were used; RCP 4.5 and RCP 8.5. A key difference between RCP and SRES is that some RCP scenarios do allow for climate initiatives. RCP 8.5 is ‘business as

Figure 14: Annual Rainfall



Source: Singh (2011)

46. The current trends and model predictions for temperature indicate that it is most likely to increase over the project lifetime and beyond. As outlined above, the best estimate is an increase in mean annual temperature of 3.5 ^{0}C over the period 1980 to 2069, which is 3.0 ^{0}C over the period 2016 to 2069.

47. The situation regarding precipitation is similar. The best estimate is an increase in annual mean total precipitation of 30% (600 mm/year) over the period 1980 to 2069, or about 34% (450 mm/year) in terms of monsoonal mean total precipitation.

48. Changes in precipitation could impact the project. Changes in rainfall intensity could have implications for design of the river training, cross drainage and storm water collection system. In summary, climate change is likely to lead to an increase in frequency and intensity of precipitation related events, such as floods, landslides, and typhoons. Sediment and river morphology processes may be influenced by these changes.

B. Vulnerability Assessment

1. General

49. The goal of a vulnerability assessment is to identify current and future vulnerabilities and understand the key determinants of this assessed vulnerability. In line with ADB practice,

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usual' whilst RCP 4.5 assumes a range of technologies and strategies are implemented for reducing greenhouse gas emissions.

'*Vulnerability refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change.'*[31]

50. The impact assessment shows the principal climate change effects likely to directly impact on the project are those related to precipitation; annual and seasonal changes and frequency and intensity of events, which gives rise to hazards (flooding, landslides and siltation).

51. Historically Phuentsholing has experienced heavy rainfall, fluvial floods (i.e. from the Amochhu), flash floods from the left bank tributaries, as well as landslides/debris flows. The experience is not well documented. Logically, development has largely been restricted in the areas that are most exposed. Although now with population growth and economic growth the city is encroaching on areas with high levels of exposure to flood hazards and erosion, principally the Amochhu Local Area Plan (LAP). Figure 15 shows the area to the north of Phuentsholing, with the LAP in the distance.

Figure 15: View looking downstream towards the LAP, following 2015 flooding

Source: Image by CDCL, July 2015. Annotated by PPTA.

52. Anecdotally, floods resulting in significant damage have been experienced in 1993, July 1996, August 2000, May 2009, July 2015[32], and July 2016. The flood in 2000 resulted in widespread damage in Phuentsholing, Pasakha and other southern cities.[33] In Phuentsholing it resulted in erosion of the river banks and abandonment of the in-river water supply intake structure. There was also significant flooding of low lying areas in Phuentsholing due to the Omchhu exceeding its capacity. The damage justified construction of a flood defence scheme

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[31] ADB. 2012. *Guidelines for Climate Proofing Investment in Agriculture, Rural Development and Food Security*. Manila

[32] Estimated peak discharge was 2,340 m^3/s.

[33] DDM, 2015. *Past Disaster Report*, Department of Disaster Management, Thimphu, 2015.

for this major left bank tributary in 2002/2003, funded under the ADB-financed "Urban Infrastructure Improvement Project".[34] Figure 16 shows the location of the Omchhu defences, sewage treatment plant (STP), approximate Amochhu bank line in 2016, and the Amochhu LAP.

Figure 16: Location plan

Source: PPTA. Annotated Google Earth image dated 19/12/14.

53. The most devastating flood in the recent history of Bhutan happened during the Cyclone Alia in 2009.[35] The damage in Phuentsholing is undocumented but anecdotally it resulted in bank erosion along the Amochhu, and damage in the Omochhu. Figure 17 shows the nature of damage to the Omchhu flood defences and repairs undertaken post the 2009 event.

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[34] ADB. 1998. *Report and Recommendation of the President to the Board of Directors: Proposed Loan to the Kingdom of Bhutan for the Urban Infrastructure Improvement Project.* Manila.

[35] Egis. 2016a. *Hydrological Modeling and Assessment for Bhutan*, part of ADB Contract No. CDTA 8623-BHU, Adapting to Climate Change through IWRM, Egis International, April 2016

Figure 17: Omchhu embankment repairs following 2009 flooding

Source: PPTA

54. The vulnerable areas include the Amochhu's left bank along much of the river reach covered by Zone A (see Figure 5 and Figure 18), as well as the active landslides and debris flows located at the toe of the hills along the left bank. Recent river bank erosion in 2015-2016 and channel migration towards Phuentsholing is focused on the reach extending along much of Zone A's river bank, from a point several hundred meters downstream of the start of Zone A, downstream to the existing STP. Current erosion/scour control measures are ad hoc and ineffective. Existing riparian infrastructure, including the recently (2015) rebuilt training walls at the Omchhu confluence were undermined and failed. The river side boundary wall for the STP is protected using gabion spurs. The riverside end of the spurs was undermined but the rest remains substantially intact, for the present time.

Figure 18: River reach that is susceptible to lateral erosion

Source: HCP[36]. Annex 4. Fig 0.2

55. The project will protect the existing town from Amochhu-related floods and riverbank erosion which currently threatens lives and livelihoods and disrupts connectivity with nearby communities. There are some caveats. Firstly, the low-lying areas between the PTDP and the foothills must be filled in the same manner as the project area to avoid back flooding from the Amochhu via the cross-drainage facilities. Secondly, the efficacy of the cross-drainage facilities in protecting the existing town from flash floods from the left bank tributaries depends, amongst other things, on (i) providing adequately sized debris dams on the tributary catchments that feed the cross-drainage facilities and (ii) regular and detailed monitoring of channels and structures, particularly prior to and during the monsoon season when flood risk is highest. Vigilant management of sediment deposition is vital to maintain conveyance capacity of the natural and engineered channels, and is necessary because Zone A effectively lengthens and flattens the cross-drainage paths. Thirdly, the existing town will still be exposed to Amochhu flood events which exceed the design event. Lastly, exposure due Omchhu-related flooding and pluvial[37] flooding will be unchanged.

56. The project will provide protection for the new town from floods and erosion, and construct urban infrastructure to allow phased urban expansion. The new town and reclaimed areas will also still be vulnerable to events which exceed the design event, with due allowance for freeboard, as discussed further below.

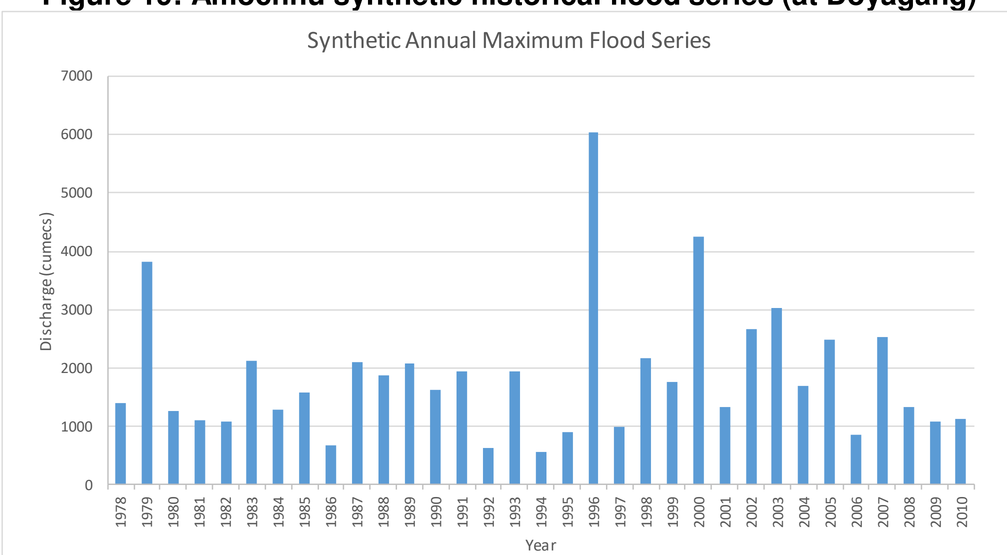
[36] HCP, *Stage 3: Integrated Detailed Project Report (IDPR) – 2nd Draft*, 12 August 2016.
[37] Local rainfall-runoff that exceeds the capacity of the local stormwater system.

2. Vulnerability Due to the Amochhu

57. Two widely accepted methods have been used to derive flood estimates for the Amochhu at Phuentsholing; flood frequency analysis using observed flood data at Hasimara, and synthetic unit hydrograph analysis.[38] The synthetic unit hydrograph estimates were slightly larger so were adopted in preference to the flood frequency estimates. The estimated flood values are 5,900 m^3/s and 7,100 m^3/s for the 1 in 50 and 1 in 100 Annual Exceedance Probability (AEP) events respectively. These estimates exclude a climate change allowance and are understood to be maximum instantaneous values applicable at Phuentsholing.[39]

58. A Detailed Project Report (DPR) has been prepared for a proposed Amochhu Hydro Power Project in 2011.[40] The concept design comprised a 540 megawatt (MW) scheme with a 195 m high concrete gravity dam located just upstream of the Doyagang bridge. The DPR included a synthetic historical flood series as part of that study.[41] Figure 19 shows the flood series to provide some context to historical flooding in the Amochhu at Doyagang, which in practical terms is representative of Phuentsholing as far as the flood protection project is concerned.

Figure 19: Amochhu synthetic historical flood series (at Doyagang)



Source: PPTA, using series included in NTPC report.

59. NTPC independently carried out a flood frequency analysis using the synthetic annual maximum flood series. The estimated flood values were 5,222 m^3/s and 6,216 m^3/s for the 1 in

[38] CWC. 1991. *Flood Estimation Report for North Brahmaputra Basin (Sub-Zone 2a)*, Central Water Commission, 1991.

[39] It is unconfirmed whether the estimates were derived at-site or at Hasimara. As the catchment area difference is relatively small, and it is conservative to adopt the estimates at Hasimara, it is acceptable to consider the estimates to be applicable at Phuentsholing without adjustment.

[40] NTPC, *Amochhu Reservoir Hydroelectric Project – Detailed Project Report*, September 2011

[41] NTPC derived the series using a composite of observed data from Dorokha, Doyagang and Hasimara. It is referred to as 'synthetic' to distinguish it from the observed series. Its derivation involved several assumptions regarding a) scaling flood values based on catchment area b) scaling up by 15% to convert average or observed daily discharges into assumed instantaneous peak discharges and c) judgement to infill some missing values. For these reasons, the peak shown for 1996 exceeds the 5,397 cumecs adopted as the maximum observed flood at Hasimara in 1996.

50 and 1 in 100 AEP events respectively. In both instances these estimates are less than the estimates adopted for PTDP, improving confidence in the PTDP estimates.

60. Climate change considerations are not included in the flood estimates for the Amochhu or cross-drainage tributaries. The PPTA recommended that an appropriate climate change factor, as discussed further below, should be applied to the design flood and the resulting value should be referred to as the 'check flood' (e.g. for the Amochhu it would be the 1 in 100 AEP including climate change). Further, the hydraulic model should be re-run with the check flood to determine the maximum water level that would eventuate. The portion of freeboard used by the climate change allowance should be quantified. The PPTA does not recommend adding the climate change allowance to the design flood and maintaining the 1m of freeboard as that would be unduly conservative.

61. Assessment of climate change impacts on flood frequency due to projected changes in extreme precipitation is very complex, comprising a series of linked models and analyses. In recognition of this, the SASEC climate change study[42] included a literature review of climate change adjustment factors,[43] concluding that the factors shown in Table 3 should be applied to the Amochhu estimates.

Table 3: Climate change factor

AEP (1 in x)	2	5	10	20	50	100	200	500	>1000
Climate change factor, f	1.5	1.45	1.4	1.33	1.23	1.15	1.08	1.03	1.0

Source: HCP (2016)

62. For example, the 1 in 100 AEP Amochhu flood is estimated to be 7,100 m^3/s, excluding climate change. The estimate would be multiplied by 1.15 to arrive at a revised estimate of 8,165 m^3/s, allowing for climate change. Similarly, the 1 in 50 AEP Amochhu flood is estimated to be 5,900 m^3/s, excluding climate change. The value would be multiplied by 1.23 to arrive at an estimate of 7,257 m^3/s, allowing for climate change. Another way of considering it, is that the 1 in 100 AEP flood based on historical observations will approximately be the 1 in 50 AEP flood in the future.

63. The sensitivity of the project[44] to climate change has been assessed in terms of the estimated peak flood discharge and resulting peak water surface level for the design event (1 in 100 AEP) with and without application of the climate change factor. A simple hydraulic calculation[45] has been undertaken at the Interim Report stage to determine the impact on peak water surface levels, allowing calculation of the residual freeboard. The results are shown in Table 4. Figure 20 shows the proposed cross section and water levels excluding climate change.

[42] ADB. 2016a. *Initial Environmental Examination, BHU: SASEC Transport, Trade Facilitation and Logistics Project*. Prepared by Department of Roads for ADB, Project Number: 47284-002, May 2016

[43] They found that a *few countries around the world have adopted policy design guidelines on climate change adjustment factors to be applied to current design estimates, owing to paucity of published guidelines on the incorporation of climate change effects in flood frequency estimation.*

[44] Assuming that all Zones (A, B, C and E) are ultimately developed.

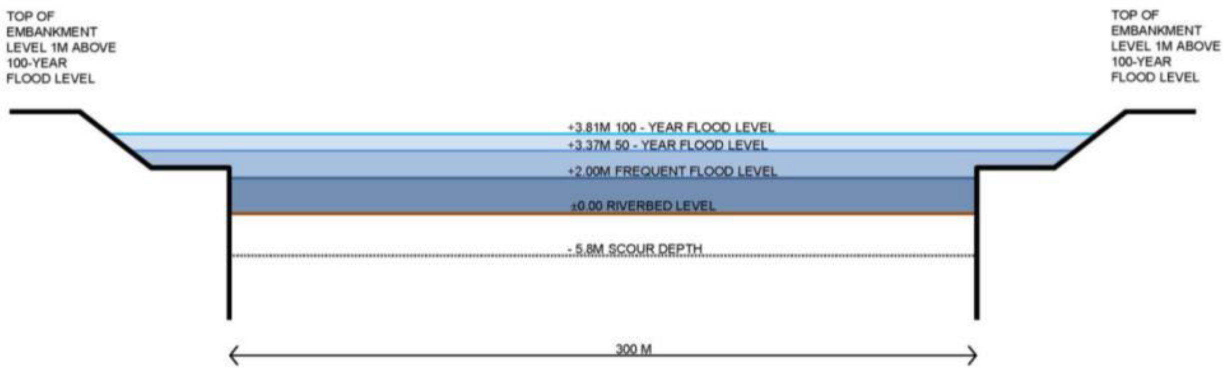
[45] The Manning's formula was used with the parameters adopted in Annex 4 of the IDPR (HCP, 2016). It is envisaged that the results of the two-dimensional hydraulic model currently being undertaken by HCP will supersede the estimates shown above (when made available to the PPTA).

Table 4: Sensitivity results for the design event

Parameter	Unit	1 in 100 AEP Excl. CC	1 in 100 AEP Incl. CC	Difference
Peak discharge	m^3/s	7,100	8,165	+15%
Water level[46]	m	3.82	4.15	9%
Freeboard	m	1.0	0.67	-33%
Mean velocity[47]	m/s	6.05	6.38	5%

Source: PPTA Consultant

Figure 20: Schematic of cross section and levels (excluding climate change)



Source: HCP (2016)

64. In summary, inclusion of a climate change allowance reduces the freeboard by 0.33 m, leaving a freeboard of 0.67 m above the estimated water level for the design event, assuming the channel bed is the same as the design profile.[48]

65. In addition to increased water surface levels, increased flood discharge (intensity and frequency) will have adverse effects on in-channel flow velocities, erosion/scour and sedimentation. Quantifying these effects is problematic and it is not practical with a reasonable degree of certainty to assess the probability or scale of such an impact (spatially). However, as outlined in the adaptation assessment there are potential adaptation measures that could be implemented should this potential become a reality.

3. Vulnerability Due to the Tributaries

66. The SASEC climate change study[49] identified that there are '*numerous small side drainages, mainly ephemeral, flowing from the slopes of the ALRP,[50] where landslides, debris*

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[46] Water level here is relative to the design bed level (assigned a datum of 0.0m). It is the nominal surface excluding any allowance for super-elevation, waves, etc.

[47] Cross section averaged velocity.

[48] The practicality of last assumption will be tested using the two-dimensional model. Sediment transport and river morphology considerations are integral to flood estimates for an active high energy river such as the Amochhu.

[49] ADB. 2016a. *Initial Environmental Examination, BHU: SASEC Transport, Trade Facilitation and Logistics Project*. Prepared by Department of Roads for ADB, Project Number: 47284-002, May 2016

flows and flash floods are more pronounced particularly during the monsoon season. Most devastating events are flash floods that develop within short periods after intense precipitation. The ALRP DPR seems not to have given much recognition of the higher risk that flash floods pose to human life and livelihoods in comparison to the more regular riverine floods that build up over days when there is heavy rainfall upstream. The tendency for flash floods to carry with them much higher debris flows with consequent higher damage to roads, power lines, bridges, buildings and other expensive infrastructure needs to be appreciated in the design of check dams, catch-water drains, cross drainages and collector drains'.

67. The PPTA concurs with the comments above, which are equally applicable to the IDPR.[51] There are several active slides and resulting debris fans that will continue to deliver significant quantities of material to the floodplain for the foreseeable future. Use of open flumes for the larger streams is preferable (as included already) to culverts. Flumes have a consequential loss of developable area but are less prone to blockage, easier to maintain and have a lower head loss. Regardless of the choice of flume or culvert, adequate space and access for removing deposited material is needed, either in detention basins/debris traps just upstream of the entry (as are currently used for existing crossing on the Phuentsholing-Samtse Road), or in the case of a flume, from the flume channel itself.

68. The Department of Roads (DOR) is currently undertaking detailed design for the Phuentsholing-Chamkuna Road (PCR) project financed under the SASEC Transport, Trade Facilitation and Logistics Project.[52] The PCR forms the eastern boundary of Zone A. DOR will design the cross drainage works upslope of the PTDP boundary in close coordination with CDCL, who remain responsible for the cross drainage works between the PTDP boundary and the Amochhu.

69. The success of the PTDP cross drainage works depends on having appropriate structures constructed as part of the PCR project (including debris traps) and them subsequently being well maintained. The PPTA has discussed the key functional requirements with DOR, and it is understood that the design is in progress. The detailed design for the PCR is due in June 2017.

70. CDCL's design proposes ducted outfalls labelled 1 to 8 and open outfalls labelled 1 to 4 in Zone A. Figures 21 and 22 show the locations. A blockage risk has been identified for the ducted outfalls due to sediment transport from the tributary fans. Following several meetings with Egis and CDCL in January, it was agreed that ducted outfalls 3, 4, 5 and 6 will be changed to open channels.[53]

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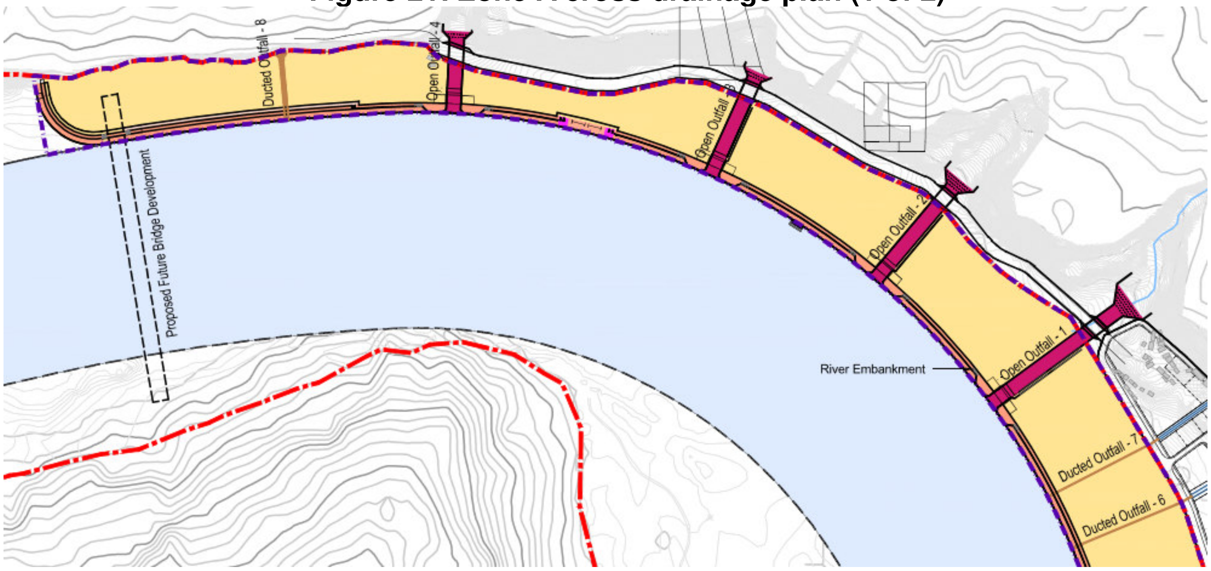
[50] The ALRP is an earlier acronym for the PTDP.

[51] HCP, *Stage 3: Integrated Detailed Project Report (IDPR) – 2nd Draft*, 12 August 2016.

[52] ADB, 2016, *Report and Recommendation of the President to the Board of Directors: Proposed Loan to Kingdom of Bhutan for the South Asia Subregional Economic Cooperation Transport, Trade Facilitation and Logistics Project.* Manila.

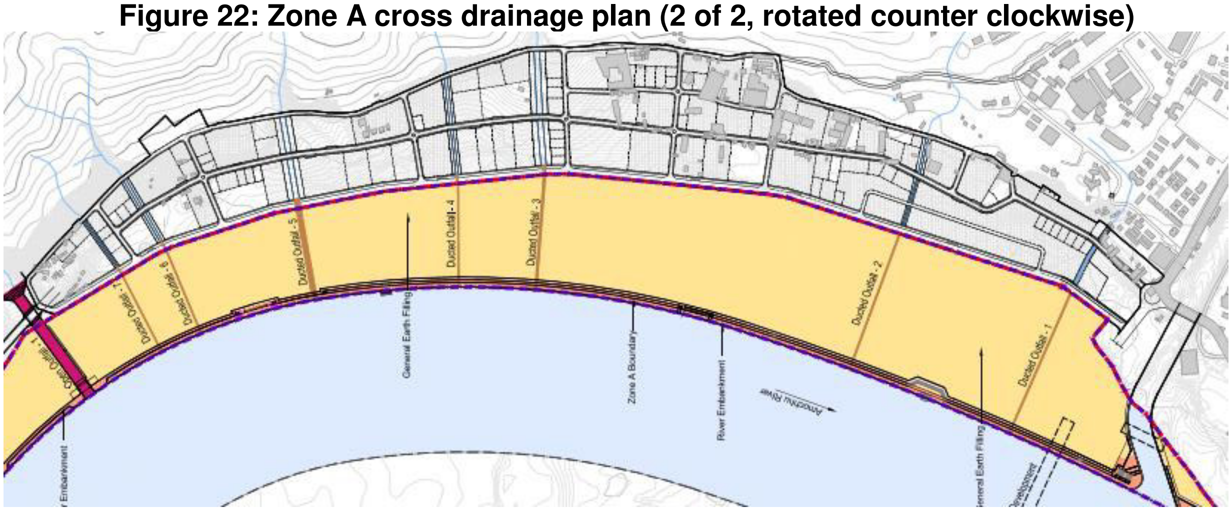
[53] PPTA, *Cross drainage recommendations*, memorandum from C Dunlop to K Dhakal, 9 February 2017.

Figure 21: Zone A cross drainage plan (1 of 2)



Source: HCP drawing ART-SW-01, 30/11/16

Figure 22: Zone A cross drainage plan (2 of 2, rotated counter clockwise)



Source: HCP drawing ART-SW-01, 30/11/16

71. The design flood of the cross-drainage channels being designed by the DOR project are based on the 50-year flood with an additional climate change factor applied. These approximate the current 100-year events. The designs of the channels will also account for the coincidence of flood events occurring within the Amochhu and cross drainage channels.

4. Vulnerability Due to Geophysical Hazards

72. The existing population of Phuentsholing at 2015 was approximately 20,400 (2015).[54] The exposure of people and property in the existing town to earthquakes is relatively high due to the high population density and predominant building type (multi-story dwellings). Exposure is increased due to the presence of critical road infrastructure, namely the Phuentsholing – Thimphu national highway. Phuentsholing is vulnerable to earthquakes due to (i) potential

[54] DHI Infra, 2015. *Review Report of Housing Needs Assessment by National Housing Development Corporation*. Thimphu.

foundation issues associated with liquefaction for buildings founded on alluvium; (ii) unsafe design and construction methods used for masonry and reinforced concrete buildings; (iii) rapid urbanization and widespread poverty; and (iv) the low capacity of the authorities, in terms of resources, to respond to a disaster. Disaster risk[55] associated with earthquakes for the existing town is therefore considered to be high, in a qualitative sense.

73. The exposure of people and property in the existing town to landslides[56] is also relatively high due to the high population density and predominant building type (multi-story). Exposure associated with the Phuentsholing–Thimphu national highway has been highlighted during previous events. Phuentsholing is vulnerable to landslides due to the unstable/young geology, steep topography, high precipitation, and formal and informal development on, and at the toe of, hillslopes in and around the existing town. Disaster risk associated with landslides for the existing town is therefore considered to be high, in a qualitative sense.

74. Development in Phuentsholing and the surrounding areas continues at a rapid pace. The estimated population at 2046 is approximately 80,000[57] including 50,000 people residing within all four new zones if development proceeds as envisaged. Disaster risk associated with earthquakes for the proposed town can qualitatively be expected to be lower than for the existing town due to: (i) a proposed lower population density; and (ii) improved building standards and control. Disaster risk associated with landslides for the proposed town can qualitatively be expected to be lower than for the existing town principally due to the remote proximity of the proposed development from the unstable hillslopes.

C. Adaptation Assessment

75. In line with ADB practice "*the purpose of adaptation assessment is to identify and prioritize the most appropriate adaptation measures to incorporate into the project. This includes the identification of strategies to minimize damages caused by the changing climate and to take advantage of the opportunities that a changing climate may present".* [58]

1. Climate Change Risks

76. Potential climate adaptation options can be classified into the following groups: (i) engineering options (structural; specifications, design standards etc.); (ii) non-engineering (management, operation, maintenance, capacity building etc.); and (iii) maintaining the status quo (i.e., 'do nothing'). The following tables outline adaption options for the potential project climate change vulnerabilities.

Table 5: Engineering options for adapting to an increase in flood risk

ID	Description	Owner	Phase	Incl.
E-1	*Material specification* - Use a high strength/durable concrete mix and increased reinforcement cover on	CDCL	Project Preparation	Yes

[55] As defined in ADB, *Reducing Disaster Risk by Managing Land Use – Guidance Notes for Planners*, 2016, disaster risk can be characterised as a function of (i) the probability of hazards of varying severity in a particular location, (ii) the people and physical assets that are situated in the location and exposed to the hazards, and (iii) the level of vulnerability of those people and assets to hazards.
[56] The focus here is on precipitation triggered landslides, but the same comments apply to earthquake triggered landslides.
[57] CDCL. 2016. *Draft Integrated Detailed Project Report.* Thimphu.
[58] ADB. 2012. *Guidelines for Climate Proofing Investment in Agriculture, Rural Development and Food Security*. Manila

ID	Description	Owner	Phase	Incl.
	areas of the river training structures which are exposed to abrasion and erosive forces (e.g. the cast in-situ wall on the outside of the bend in Zone A)			
E-2	*Material specification* - Specify riprap size and grading appropriate for the anticipated hydraulic conditions. (e.g. on the outside of the bend in Zone A)	CDCL	Project Preparation	Yes
E-3	*Dimension and capacity standards* - Review design standards for climate change affected infrastructure (river training works, cross drainage and stormwater system). Assess effects of potential increase in flood magnitudes, and if warranted, modify the standards and detailed design.	PPTA	Project Preparation	Yes
E-4	*Dimension and capacity standards* – Specify an appropriate freeboard between the estimated flood level for the design event and the top of the embankments / finished levels in land reclamation areas.	CDCL	Project Preparation	Yes
E-5	*Drainage and soil conservation* - Use bio-engineering to promote soil conservation in the project area and in areas adjacent to it, notably in the tributary catchments that feed the cross-drainage facilities	Phuentsholing Thromde	Implementation, Operation	TBA
E-6	*Protective engineering structures* - Provide adequately sized debris dams on the tributary catchments that feed the cross-drainage facilities	DOR, part of Phuentsholing-Chamkuna Road project.	Project Preparation	Yes
E-7	*Protective engineering structures* - Provide scour counter measures for cross drainage facilities.	CDCL	Project Preparation	Yes
E-8	*Protective engineering structures* - Provide scour counter measures for river training works to protect foundations.	CDCL	Project Preparation	Yes

Table 6: Non-engineering options for adapting to an increase in flood risk

ID	Description	Owner	Phase	
N-1	*Flood management* - Improve catchment and river basin management to achieve better capacity, planning and monitoring to reduce flood risk.	CDCL	Implementation	Yes
N-2	*Flood management* - Improve meteorological and hydrological data collection in the catchment to improve the database used for making decisions	CDCL	Implementation, Operation	Yes
N-3	*Infrastructure operation and maintenance planning* - Implement regular and detailed monitoring of channels and structures, particularly prior to and during the monsoon season when flood risk is highest. Vigilant management of sediment deposition is vital to maintain conveyance capacity of the natural and engineered channels.	CDCL	Operation	Yes

ID	Description	Owner	Phase	
N-4	*Master planning and land use management* – Development within the project area should avoid geologically unstable areas, flood prone areas. It should promote green zones and build in egress routes.	CDCL	Project Preparation	Yes
N-5	*Training/capacity building* - Provide training for CDCL maintenance personnel related to climate change impacts, use of climate information, weather forecasting and early warning systems.	PIC	Implementation	Yes
N-6	*Information systems* - Implement a flood early warning system (FEWS) and operate it in accordance with a flood management plan (FMP). Phuentsholing Thromde does not have an existing operational flood management plan.	CDCL, PIC	Implementation, Operation	Yes

2. Geophysical Risks

77. Disaster risk reduction, in terms of the earthquake hazard, can be achieved for new developments in Phuentsholing by using applicable building standards and control during implementation. Risks associated with landslides can be reduced with strict land use planning. The responsibly agency is the Phuentsholing Thromde.

78. Disaster risk reduction for the PTDP, in terms of the earthquake hazard and landslide hazard, will be achieved through proper land use planning (a development masterplan has been prepared for the project), application of development control regulations prepared for the project, and using applicable building standards and control during implementation. The responsibly agency will be CDCL.

79. The FEWS noted in N-6 (Table 6) will potentially be useful in the event of formation and breach of a landslide dam[59] on the Amochhu. The available warning time, and hence reduction is disaster risk for the existing town and new town, depends on the location of the landslide dam. The further upstream, the more warning time there would be.

D. Implementation

80. Most options listed in Tables 5 and 6 will be adopted in the project preparation phase. Exceptions are discussed in the following sections.

81. E-5 comprises use bio-engineering to promote soil conservation in the project area and in areas adjacent to it. Any works outside of the project boundary would be under the control of others. The Phuentsholing-Chamkuna Road project may undertake some bio-engineering. The Phuentsholing Thromde would be responsible for all other areas, if this is pursued.

82. N-1, N-2, N-5 and N-6 are related. A Flood Management Specialist will be engaged to provide advisory services to CDCL on establishing the FEWS and FMP during project implementation. The FEWS and FMP will broadly comprise the following components:

- Rainfall and water level sensors at selected locations.

[59] As noted in Section A, there is no evidence of landslide dam break flooding in the Amochhu.

- Data loggers for the rainfall and water level data.
- Satellite based transmission of the rainfall and water level data.
- Reception of the satellite transmissions at the DHMS control centre in Thimphu.
- A computer-based system to monitor the status of the rainfall and water levels, with a range of alert levels.
- A flood forecasting model to be utilised when a trigger alert level is raised.
- Reception of the data, alert levels and flood forecasting results at Thromde operations centre in Phuentsholing.
- A procedure for warning dissemination via various media.
- Procedures for action by the emergency services and the public.

83. Development of the FEWS and FMP will require close coordination with the Department of Disaster Management (DDM), Department of Hydromet Services (DHMS), and Phuentsholing Thromde, amongst others. DDM has an overview role as set out in the Disaster Management Act of Bhutan 2013. DHMS currently provides flood warning services for other locations in Bhutan and will need to be closely involved throughout specification, installation and commissioning of the FEWS. Phuentsholing Thromde will be integral to the FMP execution and will host the operations centre in Phuentsholing.

84. FEWS equipment (supply and install) will be procured by CDCL through an international competitive bidding process in accordance with ADB procedures as a goods package. Ownership, operation and maintenance of the equipment will be determined during project implementation.

85. All data from the field equipment will be sent in quasi real-time to DHMS's office in Thimphu where the flood forecasting will be carried out. All data from the control centre will be sent in quasi real-time to a dedicated room (the operations centre) in Phuentsholing. The operations centre will be used to direct responses of the various agencies and stakeholders, in accordance with the FMP.

86. The Flood Management Specialist activities, will include, but are not limited to:

- review available information related to PTDP, DDM, DHMS, and Phuentsholing Thromde, including site visits and meetings
- undertake a needs assessment of the FEWS and FMP. This should include a GIS-based geospatial risk assessment of the project area and Phuentsholing, culminating in preparation of flood hazard maps[60], highlighting existing and future[61] levels of exposure[62] and vulnerability[63].
- plan, design and specify the FEWS equipment[64] in close consultation with DHMS, taking account of the risk mapping/assessment
- assist CDCL with procurement of the works package including tender evaluation

[60] Flood data for the Amochhu should utilise the 2D hydraulic model developed by CDCL. Flood data for the Omchhu will require hydrological and hydraulic modelling carried out as part of this task.
[61] Including population growth and climate change projections.
[62] Proximity to the river/source, water velocity, flood elevation. Highlight critical infrastructure and other public assets.
[63] Condition of housing and informal settlements, for example. The poor, children, elderly and disabled.
[64] Includes field equipment, communications between the field installation and the control centre, control centre, communications between control centre and operations centre, as well as the operations centre and the authorities and the public.

- assist the PIU with supervision of installation and commissioning for the field equipment, communications equipment, and the equipment for the control centre and operations centre
- plan, develop, calibrate and operationalise a flood forecasting model in close consultation with DHMS
- prepare a combined FMP[65] for PTDP and Phuentsholing in close consultation with DDM, DHMS and Phuentsholing Thromde. The FMP should include prevention and recovery along with preparedness and response.
- undertake readiness training and testing of the FEWS and FMP in close consultation with DDM, DHMS and Phuentsholing Thromde, and prepare a Completion Report.

[65] The Flood Management Plan will form part of the Emergency Management Plan currently being considered for implementation by DDM and the Thromde. The EMP will cover other hazards such as earthquakes, landslides, fires etc.

ANNEX 1: SASEC CLIMATE CHANGE STUDY REPORT

Appendix 3: Climate Change Study Report

A: Synopsis of Literature Review

A1. Amo-chu Land Reclamation Project (ALRP), DPR 1

1. The River Toorsa, known as the Amo-chu upstream in Bhutan, flows out of Tibet into the Chumbi Valley and swiftly through western Bhutan before broadening near Phuntsholing and flowing on into India. The river has its source on Mount Pauhunri (7,128 m amsl) on the Indo-Sino border. The catchment area down to Hasimara gauging station in India, 15 km downstream of the Indo-Bhutan border, is 4,006 km2.

2. The city of Phuntsholing in Bhutan is located at a geographically and commercially strategic position on the Indo-Bhutan border. Phuntsholing lies on the left bank of the Amo-chu and with every monsoon onslaught, the land along the north-western city limits have been eroded over time exposing the town to the danger of flooding from the river.

3. With support from DANIDA, the Ministry of Works and Human Settlements and the Phuntsholing City Corporation (PCC) initiated a study entailing feasibility leading to detailed design of flood and bank protection and related works. In line with the desired objectives, the report "***Toorsa River Flood Mitigation Project - Detailed Feasibility Study and Engineering Design***" was produced in August 2007.

4. The primary outputs of the above study were:

- Primary and secondary data for the analysis of the hydrologic and geotechnical site conditions.
- Advanced mathematical model analyses of the hydrology and morphology of the river, as it is at present and as it would be with the proposed flood and bank protection works.
- Designs, drawings, quantities and costs for the works, including a road bridge and hill slope protection measures, and an implementation plan.
- A conceptual land use plan for the reclaimed area.
- Financial evaluation of the proposed works.

5. The design flood is defined as the flood for which the structures planned to protect Phuntsholing from flood and bank erosion are designed. In line with general standards in Bhutan, the statistical once in 50 year return period was adopted as the design standard. Two approaches were taken to estimate the design flood: flood frequency analysis, and synthetic unit hydrograph. The former statistical approach gave a peak discharge of 5,200 m^3/s, slightly less than the observed maximum.
(*The maximum discharge in the Toorsa river was recorded at Hasimara in India, 5,400 m^3/s in July 1996 where recordings had commenced in 1978. Compared to Doyagang river gauging station, about 10 km upstream of Phuntsholing, where discharge measurements started only in 2006, the Hasimara gauge had the longest and most reliable data on the Toorsa River.*)

6. The synthetic unit hydrograph approach was based on long term observations in catchments to railway bridges in India. The analysis yielded a hydrograph with a peak discharge of 5,900 m^3/s, with flood wave duration of 53 hours. As being the more conservative result, this was adopted for the design of the flood and bank protection works at Phuntsholing.

A2: Amo-chu Land Reclamation Project (ALRP), DPR 2

7. DHI INFRA Bhutan initiated a revision of the previous 2007 study, as the earlier study had not taken into account the proposed Amo-chu Hydro-electric Project, just some tens of kilometers upstream of Phuntsholing. It was therefore necessary to revisit the earlier hydrological and morphological studies and revalidate the designs of various components studied in 2007. The revised study "***Revision of Amo-chhu Flood Management and Land Reclamation Project Study-2007***" approved by December 2013, included impact of Amo-chu HEP on design discharge of structure proposed for bank protection, reservoir sedimentation, morphological impact, dam break, flood hazard map for discharge with different return period, study leading to detailed design of flood and bank protection, dam break, revised financial analysis, and revised construction schedule.

8. The peak discharge of 5,900 m^3/s remains as that of 2007 study. Mathematical models have been applied to analyze the impact from the Design Flood in terms of water levels and discharges, the pattern of flow velocities, sediment transport along the river, and erosion and deposition of sediment along the river bed and banks.

9. The design comprises a smoothly aligned main river channel over a reach of 9 km excavated to a width of 300 m and a depth of 2 m below the general existing bed level. The alignment and dimensions have been formulated and refined to give the minimum impact. The impact is to reduce maximum water levels along the protected reach by 0.3 m, with an increase in average maximum velocity from 3 to 4 m/s.

10. Key hydraulic parameters for flood and bank protection have been derived through mathematical model studies of the complex morphological processes of the Amo-chu. The parameters are water levels, flow velocities and bed levels resulting from potential scour through the protected reach from Phuntsholing upstream.

11. Conclusions on Design Discharge by Revised DPR, 2013

12. Studying all hydrological reports, revisiting catchment hydrology, studying reservoir operation policy and modeling moderation of flood due to Amochhu Hydro Electric Project (AHEP), and the old design in Detailed Project Report, (DPR) 2007, the following conclusions were arrived at:

- The design discharge values and their return periods of AHEP are much higher than ALRP. Therefore, there appears no reason to re-asses and re-design the ALRP.
- The discharge observations are made only once a day at 8:00am and may miss the actual peak discharge, which could occur during night or later in the day.
- Some of the major flood peaks are calculated from the rating curves developed for the sites with unstable controls. The discharge may be in error up to 30%. For example, the peak at Hasimara in 1996 is actually observed at 5,397m^3/s, and corresponds to a lower stage compared to the next highest discharge of 3,800m^3/s in 2000, which is derived from a rating curve.
- It is seen due to AHEP, maximum flood moderation of 11% will occur. To achieve that 2 m rise in water level above FRL need to be allowed. This decision can be taken after discussion with Dam monitoring authority. A close monitoring between dam monitoring authority and ALRP committee is also necessary.

- The waterway of 300 m was decided and tested in the mathematical model and was finalized. This waterway was evolved during the field observations. The observations indicated the narrowest waterway found in the vicinity of the study reach. No erosion was observed on both the banks in that reach. It is known that the highest observed flood at Hashimara gauging site was 5,400m^3/s in the year 1996. No signs of erosion were observed during the inspections of site. Therefore, the waterway of 300 m was taken as a stable waterway for the river in that reach. It may be noted that the process of evolving the stable waterway was fully based on the field observations, and subsequently confirmed by the mathematical model studies. Therefore, the changes in the design discharges, if any, cannot be co-related to the waterway provided in the design.
- The protection works of both banks were designed using the highest velocities and intensities of discharge observed in the mathematical model. These were the maximum values observed in the model within the specific reaches. It was also observed during mathematical model runs that the changes in the river discharge did not show any significant changes in the velocities and intensity of discharges. The protection works are evolved on the basis of the overall maximum values observed in a specific reach, and not on the parameters from section-to-section. Therefore, the design of protection works will not go any significant change due to small changes in the river discharges.
- Changes in the design values over different reaches of the proposed protection works were decided on the overall analysis of hydraulics and morphology of the river in the study reach, and not just on the results of mathematical model studies. Therefore, changes in division of the reaches due to changes in the design discharge would not be expected.
- In view of aforesaid points, revision of the design discharge for ALRP cannot be recommended.

A3: Second National Communication from Bhutan to the UNFCCC, Vulnerability and Adaptation Assessment, Volume I, Technical Paper, September 2011 (National Environment Commission, Bhutan)

1. Climate Baseline and Scenarios Data

13. The National Environment Commission (NEC) notes that in order to conduct vulnerability assessments in regards to the impacts of climate change, one need to have baseline climate data on two of the key climate variables, namely air temperature and precipitation at the local/regional level. Bhutan however has observed data at the Dzongkhag level that generally covers the period 1985 to 2010. But amongst the 23 Class A and Class C stations for which data are available for maximum and minimum temperature and rainfall, almost all coverage periods span from 1996-2008 (13 years) and some cover the period 1994-2008 (15 years). Besides in a number of cases there are gaps in data (missing data).

14. For climate change impacts studies, the normal convention is to use 30-year time slices. For the current or control climate scenario, and on account of data availability, the study used the 1980-2009 period from the PRECIS simulations. Moreover, these data sets were cross-checked for consistency and accuracy against observed stations data that generally cover the period 1994/96-2008 (NEC/START-SEA, 2011). As for the future scenarios the study has used two time slices, namely a short term time period (2010-2039) centered around the twenties decade and a long term time period (2040-2069) centered around the fifties decade.

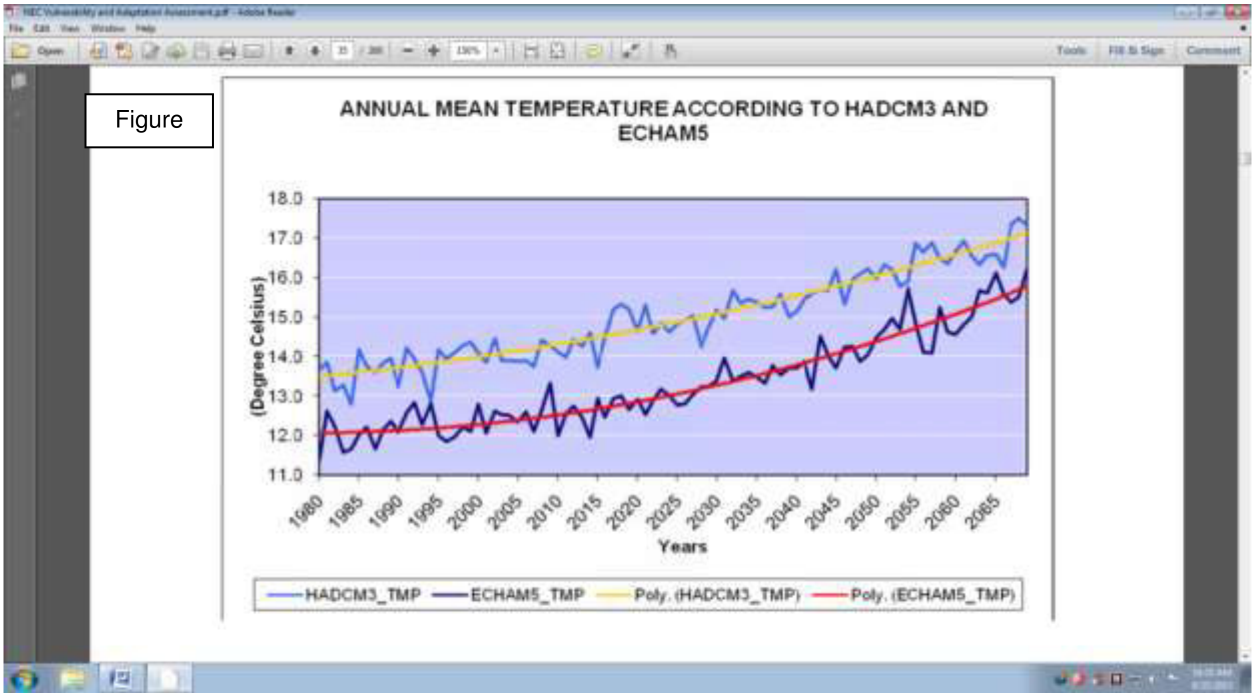
15. These future short term (2010-2039) and long term scenarios (2040-2069) of daily maximum and minimum air temperature, daily precipitation and daily solar radiation, at minimum, were supplied by NEC/START-SEA for the climate change scenarios using the PRECIS regional climate model**.** The downscaled Climate Change Scenarios (22km resolution) prepared in PRECIS was piloted by two GCMs, namely the German ECHAM5 A1B and the British HADCM3 A1B covering the period 1979-2069. Finally mapping techniques (GIS) were used to provide monthly and seasonal maps of air mean annual and seasonal air temperature and total annual and seasonal precipitation (rainfall only) for the current (1980-2009) climate and the two future (2010-2039 and 2040-2069) climate scenarios.

2. Climate Change Scenarios and Trends

16. A section of the technical report deals with the trends in mean annual and seasonal (monsoon/wet and winter/dry) temperature (^{0}C) and mean annual and seasonal (monsoon/wet and winter/dry) precipitation/rainfall (mm) for the entire surface area of Bhutan for the period 1980-2069, using simulations from the downscaled HadCM3 and ECHAM5 climate models. The monsoon/wet season is assumed to last between June to September and the winter/dry season to last between December to March. The simulations consisting of dynamically down-scaled temperature and precipitation using the PRECIS regional model was performed by NEC/START-SEA, Bangkok, Thailand. Both the HadCM3 and ECHAM5 climate models were downscaled using the SRES A1B forcing scenario. The downscaling using Precis provided climate variables diagnostics on a 22 x 22 km grid network covering Bhutan and surrounding areas.

2.1 Temperature Trend

17. The annual trends in **annual mean temperature** between 1980 and 2069, based on down-scaled simulations of both the HadCM3 and ECHAM5 climate models are shown in Figure (reproduced below as Figure 1) as yearly data and polynomially smoothed data. Both the downscaled HadCM3 and ECHAM5 climate model outputs of air temperature **show a progressive and steady increase in air temperature from 1980 to 2069.** However, there is a difference of ~ 1.5^{0}C, between the downscaled HadCM3 and ECHAM5 simulations, the HadCM3 simulations being higher. This difference was attributed to the way the two models vary certain parameters such as corrections for elevation, Bhutan being largely a mountainous country. The HadCM3 simulations therefore shows a steady increase of temperature, increasing from ~ 13.5^{0}C (1980) to ~ 17.0^{0}C (2069), a temperature increase of ~ 3.5^{0}C. On the other hand, the ECHAM5 simulations shows a steady increase of temperature, increasing from ~ 12.00 C (1980) to ~ 15.5^{0}C (2069), a similar temperature increase of ~ 3.5^{0}C.

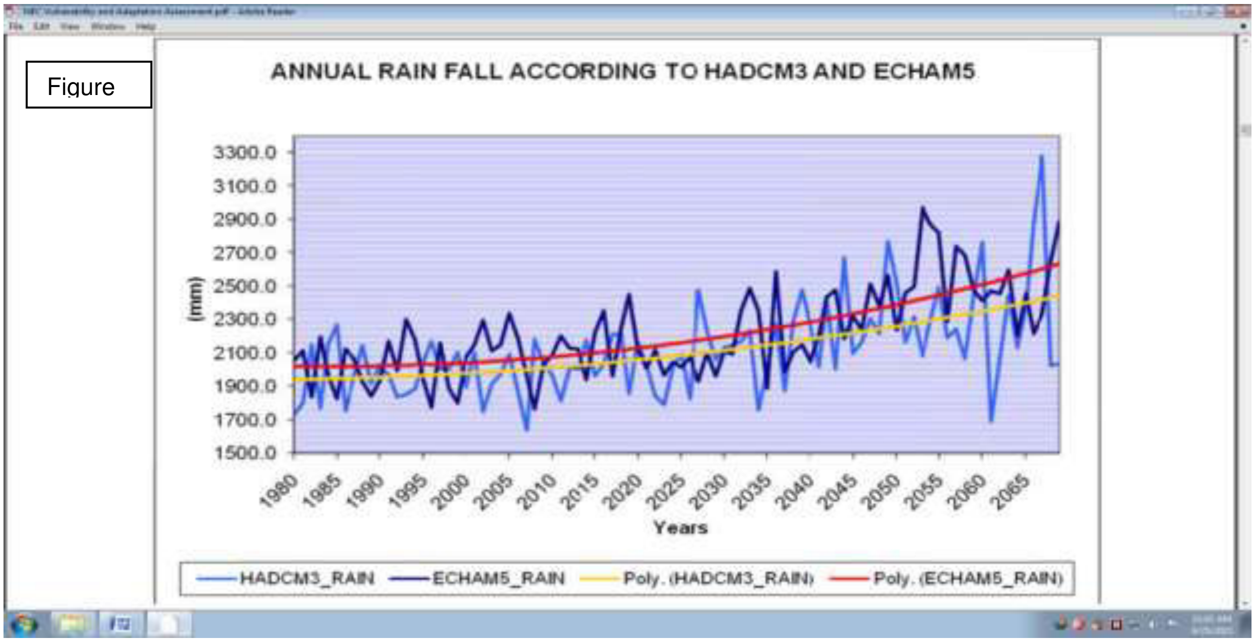


The **seasonal (monsoonal) trend in mean temperature between 1980 and 2069 show progressive and steady increase**, by ~ 3^0C by HadCM3 simulation (~19.5^0C to ~22.5^0C) and about the same by ECHAM5 simulation (~17.5^0C to ~20.5^0C).

2.2 Precipitation Trend

18. The annual trends in **annual mean total precipitation** between 1980 and 2069, based on down-scaled simulations of both HadCM3 and ECHAM5 climate models are shown in the figure reproduced below (Figure 2). Both the downscaled HadCM3 and ECHAM5 climate model outputs of precipitation/rainfall **show a progressive and steady increase in precipitation from 1980 to 2069**. However, there is difference of ~ 100 mm/year between the downscaled HadCM3 and ECHAM5 simulations, the ECHAM5 simulations showing higher, especially towards 2069. The ECHAM5 simulations show a steady increase of precipitation/rainfall increasing from ~ 2000 mm/year (1980) to ~ 2600 mm/year (2069). The HadCM3 simulations also show increasing trend from ~1900 mm/year (1980) to ~ 2400 mm/year (2069).

19. **The seasonal (monsoonal) trend in monsoonal mean total precipitation between 1980 and 2069 show progressive and steady increase**, by ~ 350 mm/year by HadCM3 simulation (~1150 mm/year to ~1500 mm/year) and ~450 mm/year by ECHAM5 simulation (~1300 mm/year to ~1750 mm/year).



B: Climate Change Resilient Approach

B1: The Amo-chu Design Flood Discharge

20. Today, there is serious concern throughout the world that large flood events may be occurring at greater than expected rates and that existing flood frequency estimates may not be sufficient to address anomalies due to climate trends. The DPRs of the ALRP cited earlier make no mention of any approaches to formulating and implementing the project for climate change adaptation. It is widely recognized that changes in climate will threaten the efficacy, adequacy, and durability of flood control structures and their continued services. Increases in the intensity and frequency of floods could overwhelm these structures, causing them to fail and any failure of flood control structures can result in dire consequences on human lives and destruction to the services and investments made.

21. The design flood, which is the flood for which the structures planned to protect ALRP from flood and bank erosion are designed, is said to be in line with general standards in Bhutan; the statistical once in 50 year return period has been adopted as the design standard. Two approaches used in the DPR to estimate the design flood are the flood frequency analysis and synthetic unit hydrograph. The former statistical approach gave a peak discharge of 5,355m^3/s, almost same as observed maximum at Hasimara just 20 km south in India. The synthetic unit hydrograph approach was based on long term observations in catchments to railway bridges in India. The analysis yielded a hydrograph with a peak discharge of 5,900m^3/s, with a flood wave duration of 53 hours.

22. Assessment of climate change impacts on flood frequency due to projected changes in extreme precipitation are very complex comprising of a series of linked models and analyses. The basis for all methodologies is climate change projections from large-scale Global Climate Models (GCMs), which model coupled atmospheric-oceanic processes for historical and future periods. The GCM model runs are based on climate forcing scenarios representing various alternatives as to how society and technology will develop through the 21st century (and in some cases beyond) and the impacts this will have on greenhouse gas emissions and

concentrations. Examples of climate forcing scenarios include the IPCC SRES scenarios and the newer RCP (Representative Concentration Pathways) scenarios. Output from GCMs, typically having grid cell sizes of 100 – 250 km, is generally too coarse for direct analyses of flood generating processes, and further processing is required before likely changes can be assessed. This further processing takes the form of a dynamical downscaling using a regional climate model (RCM) and/or some form of statistical processing (including statistical downscaling and bias correction) to obtain suitable data for use in further analyses and modeling.

23. Climate projections at a local level are highly uncertain. Given that uncertainty, the alternative is to look at several plausible future scenarios of flood risk based loosely on findings in the literature to provide some bounds on how potential changes in flood risk could translate into economic damages. These scenarios are not meant to represent any particular future reality, but instead are used to generate order-of-magnitude estimates of climate resilience.

24. A few countries around the world have adopted policy design guidelines on climate change adjustment factors to be applied to current design estimates, owing to actual paucity of published guidelines on the incorporation of climate change effects in flood frequency estimation. A review of applied methods in Europe for flood frequency analysis[42] in a changing environment indicate a gap between the need for considering climate change impacts in design and actual published guidelines that incorporate climate change in extreme precipitation and flood frequency.

25. A few examples of policy design guidelines that prescribe a “climate change factor” in the stationary design estimates adopted in Europe are:

- In the UK like elsewhere, statistical procedures for flood frequency analysis are currently based on assumptions of stationarity. However, a number of procedures exist to adjust design flow estimates for the perceived influence of climate change and land-use. Considering the effect of climate change on design flood estimates a safety margin of 20% is applied, as recommended by Defra (2006), to compensate for climate change with a time horizon until 2085.
- In Germany, the two federal states of Bavaria and Baden-Württemberg have both introduced climate change allowances to be applied for design flood estimates. In Bavaria a factor of +15% is added to the 100-year estimate, whereas Baden-Württemberg have adopted climate factors varying between 0% and +75%, depending on the region and the return period (Hennegriff *et al.*, 2006).
- In Norway, regional factors of 0%, 20% and 40% increase of design flood estimates derived assuming stationary conditions are recommended based on consideration of region, location (inland or coastal catchment), and prevailing flood season. For all catchments with a catchment area less than 100km^2, a default increase of 20% is recommended, reflecting evidence that short-term extreme precipitation will increase throughout the country under a future climate, and that smaller catchments are most vulnerable to this increase (Lawrence and Hisdal, 2011).
- In Denmark, Arnbjerg-Nielsen (2008) published climate factors for use with existing IDF curves in Denmark. The guidelines prescribe climate factors of 1.2, 1.3 and 1.4 (20%, 30% and 40%) when estimating design rainfall of 2, 10, and 100-year, respectively. While recognising that the effects might vary for different

[42] FLOODFREQ Cost Action ESO901; European Cooperation in Science and Technology, Center for Ecology and Hydrology, 2013; http://www.cost-floodfreq.eu

durations and geographical locations, these effects were considered secondary in relation to return periods, and thus, not considered.

- The Swedish Water & Wastewater Association (SWWA, 2011) published guidelines for a regional climate factor, multiplying design rainfall totals with between 1.05 – 1.3 depending on the region

26. In a paper on the effect of climate change on flood risk[43], the states of Baden-Wuerttemberg and Bavaria as well as the German weather service initiated the joint project KLIWA (climatic change and consequences for water management) in 1999, which was to examine the influence of climatic scenarios. In this joint project, so-called climatic factors were determined with which regionally dependent peak discharge quantities for different occurrence probabilities needed to be increased, in order to be able to consider the climatic changes. The introduction of a climate-change factor *f* was recommended as under:

Return Period (year)	2	5	10	20	50	100	200	500	>1000
Climate Change Factor, *f*	1.5	1.45	1.4	1.33	1.23	1.15	1.08	1.03	1.0

27. The current peak discharge determined is multiplied by the climate change factor *f* to arrive at the design discharge under climate change.

28. For instance, the design "1 in 50 year return period" flood of Amo-chu determined by the DPR 1 and 2 is 5,900 m^3/s. Using the recommendation from above, the climate change factor is 1.23 which gives an estimated climate change discharge of 5,900 x 1.23 = 7,257 m^3/s. DPR 2, page 22 on design Flood projects a 100-year flood estimate of 7,100m^3/s, which is to say that a 100 –year flood nearly equates to a 50-year flood under a stressed climate.

29. It is recommended to seriously reconsider the design parameters of the ALRP flood protection works to take into account the uncertainties associated with climate change by **adopting a 1 in 100-year flood** rather than the adopted standard 1 in 50 as given in the DPR.

30. To reduce climate change impacts on flood control structures and the resulting damage and destruction to communities and infrastructure in the reclaimed land, the project authority must adapt flood control structures to future climate stressors. The resilience of flood control structures can be increased in many ways as experts see fit. Different options exist to mitigate the impacts of these climate stressors, including structural changes (e.g., changes to embankment heights and slopes) and policy changes (e.g., changes to zoning codes, relocation, designing redundancy plans).

B2: The Small Side Drainages

31. There are numerous small side drainages, mainly ephemeral, flowing from the slopes of the ALRP, where landslides, debris flow and flashfloods are more pronounced particularly during the monsoon season. Most devastating events are flashfloods that develop within short periods after intense precipitation and or cloudbursts turning a minute drainage into a thundering wall of water that sweeps away everything in its path.

[43] The Effect of Climate Change on the Flood Risk – example of a section of River Neckar; Andreas Kron, Institute for Water and Water Resources Management, University of Karlsruhe; (*Forum DKKV/CEDIM:* ***Disaster Reduction in Climate Change*** *15./16.10.2007, Karlsruhe University); e-mail: kron@iwg.uka.de, phone: +49/721-608-8421*

32. The ALRP DPR seems not to have given much recognition of the higher risk that flash floods pose to human life and livelihoods in comparison with the more regular riverine floods that build up over days when there is heavy rainfall upstream. The tendency for flash floods to carry with them much higher debris flows with consequent higher damage to roads, power lines, bridges, buildings, and other expensive infrastructure needs to be appreciated in the design of check dams, catch-water drains, cross-drainages and collector drains.

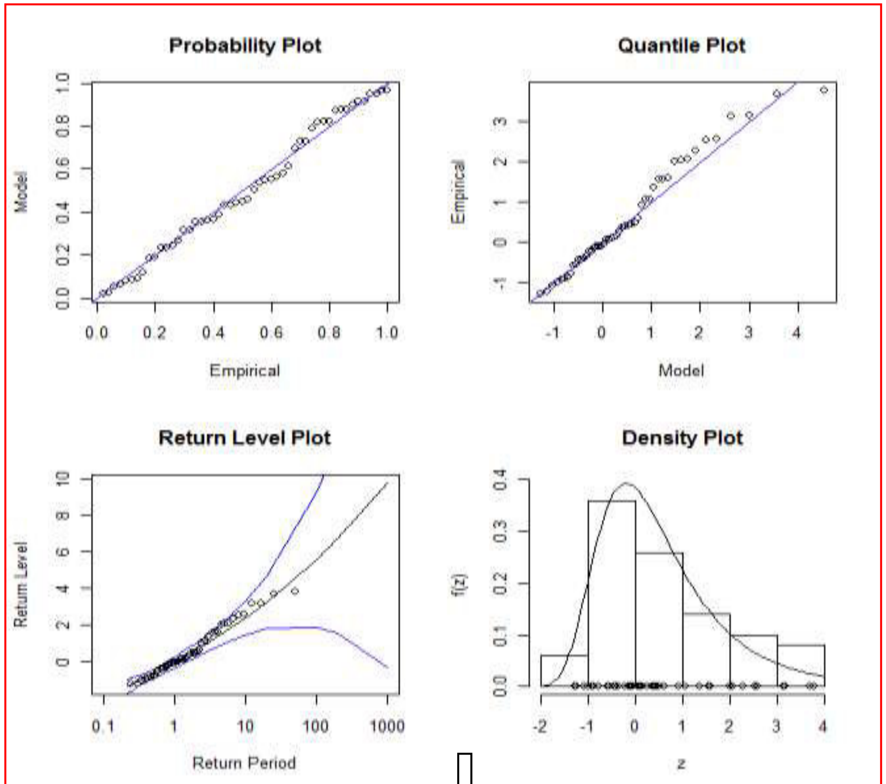
33. The catchment areas of the small drainages along the hillslopes are reported to range from 0.35 and 1.35km^2, with corresponding discharges stated as ranging from 2.5 to 12 m^3/s. Cross drains discharging between 5 and 10m^3/s of flow have been considered in the design. However, a revisit of rainfall-runoff processes may be necessary in view of changing climate. In this assessment, an extreme value (EV) assessment of the precipitation recorded at Phuntsholing Class A met station showing Intensity-Depth-Frequency (IDF) curves and a Depth-Duration (DD) table are developed under a changed climate as approximated by a positive shift in the location parameter of the frequency distribution through use of "*Extremes Toolkit Ver. 1.60*". *(See Box 1).*

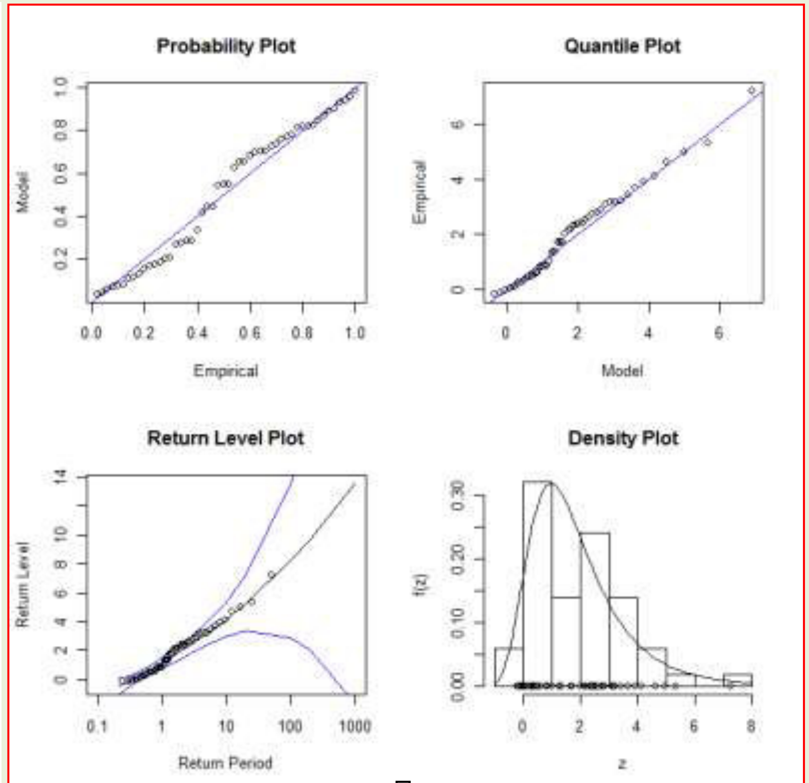
Box 1 Annual Maximum (AM) Rainfall Frequency Analysis

1. Annual Maximum Series of 24-hour Rainfall, mm, (1996-2013) – Phuntsholing Class-A Met Station

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean	Stdev	N	Q1	Q2
195.3	194.5	227.7	185	495.3	132.6	197.2	200	174.8	191	97	212	125	120.8	155	130.1	170	162.5	187.0	84.8	18	138.2	196.7

2. Data Simulated from a GEV Distribution in Extremes Toolkit Ver. 1.60





GEV simulated data generated, Stationarity
Parameters: μ: 0 Trend: 0 σ: 1 ξ: 0.2
GEV Fit
L-moments (stationary case) estimates (used to initialize MLE optimization routine):
Location (μ): -0.07868346 Scale (σ): 1.001435 Shape (ξ): 0.0624423
Likelihood ratio test (5% level) for ξ=0 does not reject EV Type I, Gumbel hypothesis.
Likelihood ratio statistic is 0.677147 < 3.841459 1 df chi-square critical value.
p-value for likelihood-ratio test is 0.4105709

GEV Simulated Data Generated, Non Stationarity
Parameters: μ: 0 Trend: 0.045 σ: 1 ξ: 0.2
GEV Fit
L-moments (stationary case) estimates (used to initialize MLE optimization routine):
Location (μ): 1.159830 Scale (σ): 1.296229 Shape (ξ): 0.009626862
Likelihood ratio test (5% level) for ξ=0 does not reject Gumbel hypothesis.
Likelihood ratio statistic is 0.5488624 < 3.841459, 1 df chi-square critical value.
p-value for likelihood-ratio test is 0.4587829

3. Estimates of 24-hr Maximum Precipitation (mm) for Various Return Periods (Stationarity vs. Non-Stationarity)

Sample mean, $\bar{x}$		187.0	
Sample StDev, s		84.8	
Return Period, T (year)	Frequency Factor $K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772+\ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\}$	Rainfall (mm) under Stationarity $X_T = \bar{x} + K_T s$	Rainfall (mm) under Non-Stationarity; Trend in location parameter $X_T = \bar{x} + K_T s$
2	-0.1643	173.1	228.5
5	0.7195	248.0	303.4
10	1.3046	297.7	353.0
20	1.8658	345.3	400.6
50	2.5923	406.9	462.2
100	3.1367	453.1	508.4
200	3.6791	499.1	554.4

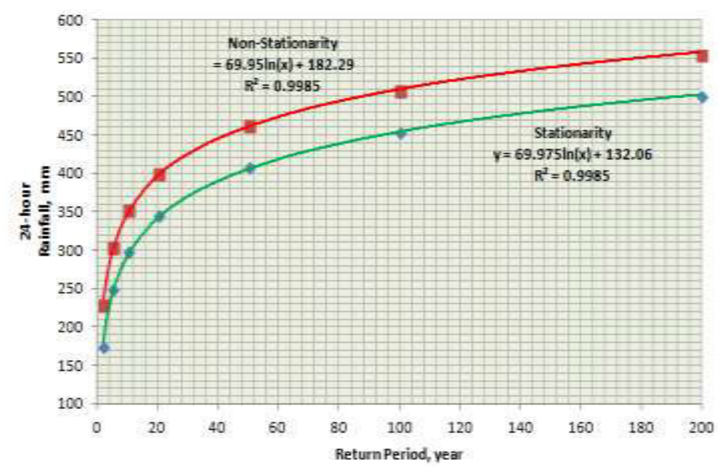


Figure 1 Maximum 24-hr Precipitation under Various Return Periods (Stationarity vs. non-Stationarity)

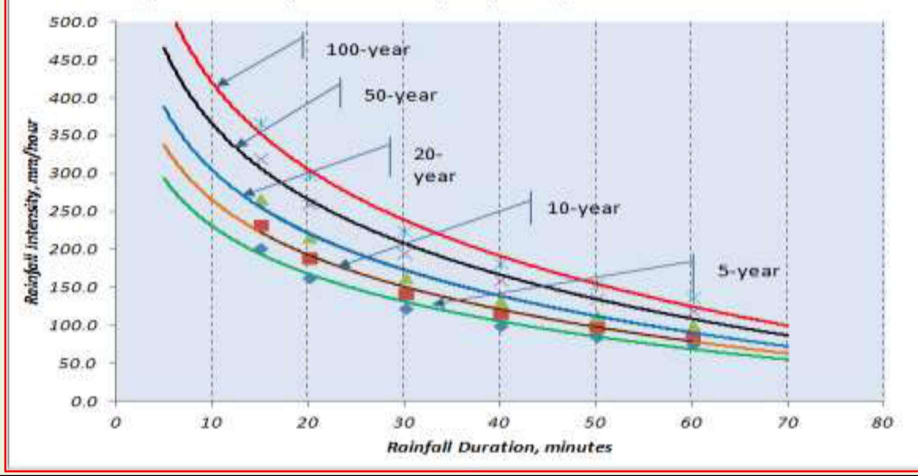
3. Intensity-Duration-Frequency (IDF), i.e., expected average rainfall depth that falls per specific time duration, under Non-Stationarity

IDF Method		$P_t^T = C\frac{T^{0.2}}{D^{0.71}}(P_{24}^2)^{0.33}$	*Ref: Kouthyari and Garde (1992), Indian Met Divison(IMD)*
P_t^T	=	*Rainfall intensity in mm/hour for T-year return period, and t-hours duration*	
C	=	*constant having value 9.1 for North East India (Assam & W. Bengal)*	
P_{24}^2	=	*2-year return period, 24 hour maximum rainfall, mm*	

Return Period, year	IDF Estimator Eqs. for Rainfall Intensity, mm/hour
100	*y = -151.9ln(x) + 736.82*
50	*y = -132.3ln(x) + 641.44*
20	*y = -110.1ln(x) + 534.03*
10	*y = -95.87ln(x) + 464.9*
5	*y = -83.46ln(x) + 404.72*

Rainfall Duration D, min	5-year	10-year	20-year	50-year	100-year
	Rainfall Intensity, mm/hr				
15	201.7	231.7	266.1	319.7	367.2
20	164.4	188.9	217.0	260.6	299.4
30	123.3	141.6	162.7	195.4	224.5
40	100.5	115.5	132.6	159.3	183.0
50	85.8	98.6	113.2	136.0	156.2
60	75.4	86.6	99.5	119.5	137.2

Figure 2: Intensity-Duration-Frequency Curve for Various Return Periods



4. Depth-Duration- (DD) Estimates of Rainfall

DDF Method	$P_t = P_{24}^T (\frac{T}{24})^{0.33}$	Ref: Rathnam et.el, IMD, 2000
where	P_{24}^T	= 24 hour precipitation for T-year return period
	P_t	= required rainfall depth for the duration t hour, mm

Return Period	5	10	20	50	100
Rainfall Duration D, hours	Rainfall Depth, mm				
0.25	66.4	77.2	87.6	101.1	111.2
0.33	73.0	85.0	96.4	111.3	122.4
0.50	83.6	97.3	110.4	127.3	140.1
0.67	92.0	107.0	121.5	140.1	154.1
0.83	99.1	115.3	130.8	151.0	166.0
1	105.3	122.5	139.0	160.4	176.4
2.00	132.6	154.3	175.1	202.1	222.2
24	303.4	353.0	400.6	462.2	508.4

Note: As is the case with all types of modeling, either statistically-derived or based on numerical simulation models, estimates obtained using flood frequency analysis are associated with uncertainty. For the analysis of historical time series, the observed data can have significant error or bias and the lack of a perfect hydrological model fit to peak flows can also introduce error in the analysis. Flood frequency analysis is also based on the assumptions that the events analyzed are independent of each other, that they represent the same flood generating mechanism, and that there are no trends in the sequence of events. These assumptions are rarely fully satisfied in practice, and thus, deviations from these assumptions also introduce error. In addition, the choice of the extreme value distribution used for the analysis, the methods used to estimate the model parameters, and the techniques for plotting events introduce uncertainty. As is true for all statistical analyses, uncertainty in the statistical model parameters increases as the number of observations available for analysis decreases. In flood frequency analysis, uncertainty increases with increasing return period, due to the larger discrepancy between the length of the record used for the analysis and the return period.

ANNEX 2: AWARE RISK ASSESSMENT

01

Introduction

This report summarises results from a climate risk screening exercise. The project information and location(s) are detailed in Section 02 of this report.

The screening is based on the Aware[TM] geographic data set, compiled from the latest scientific information on current climate and related hazards together with projected changes for the future where available. These data are combined with the project's sensitivities to climate variables, returning information on the current and potential future risks that could influence its design and planning.

Project Information

PROJECT NAME:	DEMO: Amochhu Land Development and Township Project
SUB PROJECT:	Phuentsholing River Training
REFERENCE:	TA 9140 BHU
SECTOR:	Urban flood protection
SUB SECTOR:	Fluvial defences
DESCRIPTION:	The proposed Amochhu Land Development and Township Project will develop 160 hectares (ha) of riparian land near the city of Phuentsholing that is located adjacent to the Amochhu River on Bhutans southwestern border with India. The project will provide protection from floods and erosion, and construct smart urban infrastructure to allow phased urban expansion. A modern township will be designed on modern sustainable principles of equity, livability, and competitiveness, and it will be integrated into the fabric of the existing municipality and preserve Bhutans unique architectural heritage. The project will also protect the existing and new towns from floods and riverbank erosion which currently threatens lives and livelihoods and disrupts connectivity with nearby communities.

02

Chosen Locations

1) Bhutan
2) India
3) India

03 Project Risk Ratings

Below you will find the overall risk level for the project together with a radar chart presenting the level of risk associated with each individual risk topic analysed in Aware^{TM}. Projects with a final "High risk" rating are always recommended for further more detailed climate risk analyses.

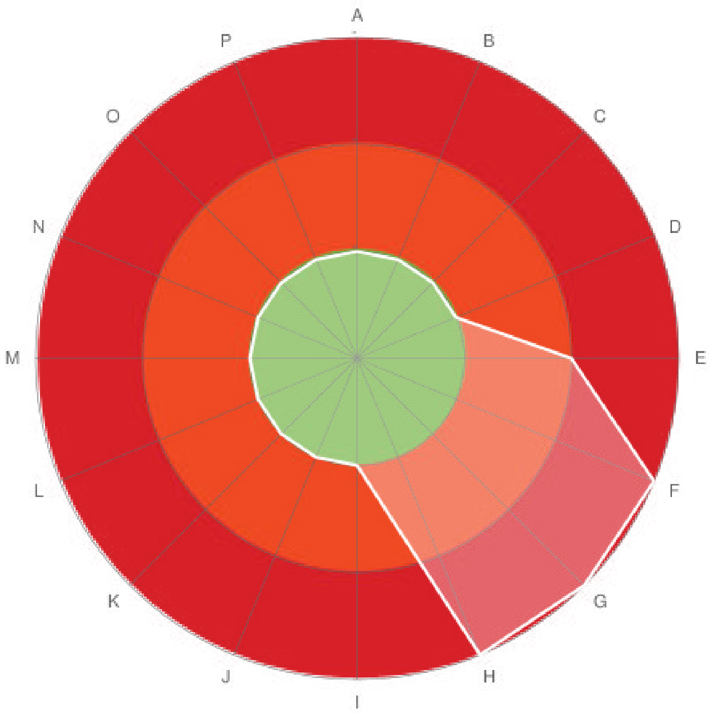
The radar chart provides an overview of which individual risks are most significant. This should be used in conjunction with the final rating to determine whether the project as a whole, or its individual components, should be assessed in further detail. The red band (outer circle) suggests a higher level of risk in relation to a risk topic. The green band (inner circle) suggests a lower level of risk in relation to a risk topic.

In the remaining sections of this report more detailed commentary is provided. Information is given on existing and possible future climate conditions and associated hazards. A number of questions are provided to help stimulate a conversation with project designers in order to determine how they would manage current and future climate change risks at the design stage. Links are provided to recent case studies, relevant data portals and other technical resources for further research.

Final project risk ratings

High Risk

Breakdown of risk topic ratings



- A) Temperature increase
- B) Wild fire
- C) Permafrost
- D) Sea ice
- E) Precipitation increase
- F) Flood
- G) Snow loading
- H) Landslide
- I) Precipitation decrease
- J) Water availability
- K) Wind speed increase
- L) Onshore Category 1 storms
- M) Offshore Category 1 storms
- N) Wind speed decrease
- O) Sea level rise
- P) Solar radiation change

04
HIGH
RISK

FLOOD

ACCLIMATISE COMMENTARY

Our data suggest that the project is located in a region which has experienced recurring major flood events in the recent past. A high exposure in Aware means that between 1985 and 2010 there have been more than one significant, large-scale flood event in the region. This is based on post-processed data from the Dartmouth Flood Observatory at the University of Colorado.

The risk and type of flooding is dependent on local geographical factors including:
• Proximity to the coast and inland water courses
• Local topography
• Urban drainage infrastructure
• Up to date information on flood risk worldwide is available online, for example UNEP / UNISDR's Global Risk Data Platform.

1. What the science says could happen in the future and what does this mean for the design of my project?

• Climate change is projected to influence the frequency and intensity of flood events.
• Existing engineering designs may not take into consideration the impact of climate change on the risks from flooding. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.
• If flooding is identified as a potential problem for the project, it is recommended that a more localised and in-depth assessment is carried out. This information can then be used to inform the project design process if necessary.

2. As a starting point you may wish to consider the following questions:

Q1 Would the expected performance and maintenance of the project be impaired by flooding?
Q2 Is there a plan to integrate climate change into a flood risk assessment for the project?
Q3 Will the project include continuity plans which make provision for continued successful operation in the event of floods?

3. What next?

• See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
• Click here or here for the latest news and information relating to floods and climate change.

I have acknowledged the risks highlighted in this section.

05

HIGH RISK

SNOW LOADING

ACCLIMATISE COMMENTARY

Our data suggest that the project is located in a region where snow is commonly observed and future precipitation may also increase (2050s). This is based on snow extent data for the northern (1967 – 2005) and southern hemispheres (1987 – 2002) from the US National Snow and Ice Data Centre (NSIDC) in addition to precipitation projections from 16 GCMs. Up to date information on snow conditions worldwide is available online from the NSIDC.

1. What the science says could happen in the future and what does this mean for the design of my project?

• The impact of increasing precipitation at higher latitudes could represent an increased risk of snow loading which could impact on the structural integrity of buildings and other infrastructure.
• Existing design standards may not take into consideration the impact of climate change on snow loading risk. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.
• If increased snow loading could be a problem for the project, it is recommended that a more localised and in-depth assessment is carried out. This information can then be used to inform the project design process if necessary.

2. As a starting point you may wish to consider the following questions:

Q1 Would the expected performance and maintenance of the project be impaired by heavy snow falls?
Q2 Are there any plans to integrate climate change into a snow loading risk assessment for the project?
Q3 Will the project include continuity plans which make provision for continued successful operation in the event of disruption from heavy snow?

3. What next?

• See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
• Click here or here for the latest news and information relating to snow and climate change.

☑ I have acknowledged the risks highlighted in this section.

06
HIGH RISK

LANDSLIDE

ACCLIMATISE COMMENTARY

• Our data suggest that the project is located in a region which is at risk from precipitation induced landslide events. A high exposure in Aware means that based on slope, lithology, geology, soil moisture, vegetation cover, precipitation and seismic conditions the area is classed as ‘medium’ to ‘very high’ risk from landslides. This is based on post-processed data from UNEP/ GRID-Europe.
• Risk is locally influenced by other factors, for example local slope and vegetation conditions as well as long term precipitation trends. If landslides are identified as a potential problem for the project, it is recommended that a more localised and in-depth assessment is carried out. This information can then be used to inform the design process if necessary.
• Up to date information on landslide risk worldwide is available online, for example UNEP / UNISDR's Global Risk Data Platform.

1. What the science says could happen in the future and what does this mean for the design of my project?

• Climate change is projected to influence landslide risk in regions where the frequency and intensity of precipitation events is projected to increase.
• Existing engineering designs may not take into consideration the impact of climate change on the risk of landslides. Previously affected areas may suffer from more frequent and severe events. See "Critical thresholds" in the "Help & glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

2. As a starting point you may wish to consider the following questions:

Q1 Would the expected performance and maintenance of the project be impaired by landslides?
Q2 Will assets or operations associated with the project be in elevated areas or close to slopes?
Q3 Is there a history of landslides in the local area where the project is proposed?
Q4 Are there any plans to integrate climate change factors into a landslide risk assessment for the project?
Q5 Will the project include continuity plans which make provision for continued successful operation in the event of landslides?

3. What next?

• See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
• Click here or here for the latest news and information relating to landslides and climate change.

☑ I have acknowledged the risks highlighted in this section.

07
MEDIUM RISK

PRECIPITATION INCREASE

Would an increase in precipitation require modifications to the design of the project in order to successfully provide the expected services over its lifetime?

Chosen Answer

Yes - a little.

The design of the project may have to be slightly modified to cope with the impact of increased precipitation.

ACCLIMATISE COMMENTARY

1. What does this mean for the design of my project?

• There is a potential for an increase in incidences where current design standards will not be sufficient. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

• The design, operational and maintenance standards should be reviewed - take into consideration current impacts of heavy precipitation events as well as potential future changes.

2. How could current heavy precipitation affect the project even without future climate change?

• Seasonal runoff may lead to erosion and siltation of water courses, lakes and reservoirs.
• Flooding and precipitation induced landslide events.
• In colder regions, seasonal snow falls could lead to overloading structures and avalanche risk.
• If our data suggests that there are existing hazards associated with heavy precipitation in the region, they will be highlighted elsewhere in the report. This may include existing flood and landslide risks.

3. What does the science say could happen by the 2050s?

• Climate model projections do not agree that seasonal precipitation will increase in the project location which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty" in "Help and glossary" at the end of this report). On the other hand, this could also mean precipitation patterns are not expected to change or may even decrease (see elsewhere in the report for more details of projections related to precipitation decrease).
• If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

4. What next?

1. See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
2. Click here or here for the latest news and information relating to water and climate change.

I have acknowledged the risks highlighted in this section.

08

LOW
RISK

TEMPERATURE INCREASE

Would an increase in temperature require modifications to the design of the project in order to successfully provide the expected services over its lifetime?

Chosen Answer

No - modifications are not required.

The design of the project would be unaffected by increases in temperature.

ACCLIMATISE COMMENTARY

1. What does this mean for the design of my project?

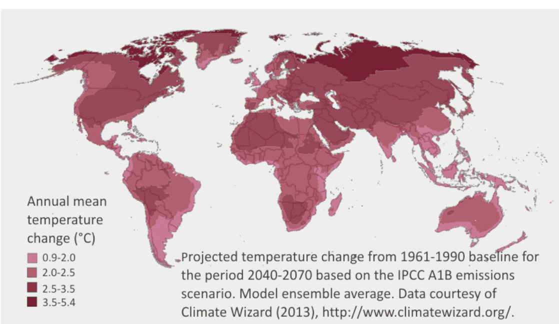
• Even though you have suggested that project designs would not be sensitive to rising temperatures, it is worth considering existing temperature related hazards in the region where the project is planned.
• There is a potential for an increase in incidences where current design standards will not be sufficient. See "Critical thresholds" in the "Help and glossary" section for further details on how a changing climate can impact on critical thresholds and design standards.

• The design, operational and maintenance standards should be reviewed - take into consideration current impacts of high temperatures as well as potential future changes.

2. How could current high temperatures affect the project even without future climate change?

• Heatwaves put stress on buildings and other infrastructure, including roads and other transport links. In cities, the ‘urban heat island’ can increase the risk of heat related deaths.
• Warm weather can raise surface water temperatures of reservoirs used for industrial cooling. In addition, this could impact local eco-systems, improving the growing conditions for algae and potentially harmful micro-organisms in water courses.
• Heatwaves can have an impact on agricultural productivity and growing seasons.
• High temperatures can have implications for energy security. Peak energy demand due to demand for cooling can exceed incremental increases on base load in addition to the risk of line outages and blackouts.
• Human health can be affected by warmer periods. For example, urban air quality and disease transmission (e.g. malaria and dengue fever) can be impacted by higher air temperatures.
• Wildfire risk is elevated during prolonged warm periods that dry fuels, promoting easier ignition and faster spread.
• Permafrost and glacial melt regimes as impacted by warm periods.
• If our data suggests that there are existing hazards associated with high temperatures in the region, they will be highlighted elsewhere in the report. This may include existing wildfire risks as well as areas potentially impacted by permafrost and glacial melt.

3. What does the science say could happen by the 2050s?



Projected temperature change from 1961-1990 baseline for the period 2040-2070 based on the IPCC A1B emissions scenario. Model ensemble average. Data courtesy of Climate Wizard (2013), http://www.climatewizard.org/.

• Climate model projections do not agree that seasonal temperature will increase beyond 2 ˚C in the project location.
• If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada’s Canadian Climate Change Scenarios Network for scatter plots of expected changes.

4. What next?

1. See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
2. Click here or here for the latest news and information relating to temperature and climate change.

☑ I have acknowledged the risks highlighted in this section.

09

LOW RISK

PRECIPITATION DECREASE

Would a decrease in precipitation require modifications to the design of the project in order to successfully provide the expected services over its lifetime?

Chosen Answer

No - modifications are not required.

The design of the project would be unaffected by decreases in precipitation.

ACCLIMATISE COMMENTARY

1. What does this mean for the design of my project?

• Even though you have suggested that designs would not be affected by a decrease in precipitation, it is worth considering existing precipitation related hazards in the region where the project is planned.

2. How could current heavy precipitation affect the project even without future climate change?

• Decreased seasonal runoff may exacerbate pressures on water availability, accessibility and quality.
• Variability of river runoff may be affected such that extremely low runoff events (i.e. drought) may occur much more frequently.
• Pollutants from industry that would be adequately diluted could now could become more concentrated.
• Increased risk of drought conditions could lead to accelerated land degradation, expanding desertification and more dust storms.
• If our data suggests that there are existing hazards associated with decreased precipitation in the region, they will be highlighted elsewhere in the report. This may include water availability and wildfire.

3. What does the science say could happen by the 2050s?

• Climate model projections do not agree that seasonal precipitation will decrease in the project location which could indicate a relatively high degree of uncertainty (see the section "Model agreement and uncertainty" in "Help and glossary" at the end of this report). On the other hand, this could also mean precipitation patterns are not expected to change or may even increase (see elsewhere in the report for more details of projections related to precipitation increase).
• If you want to know more about projected changes in the project location across a range of GCMs and emissions scenarios please refer to The Nature Conservancy's Climate Wizard for detailed maps and Environment Canada's Canadian Climate Change Scenarios Network for scatter plots of expected changes.

4. What next?

1. See the section "Further reading" in "Help and glossary" at the end of this report which lists a selection of resources that provide further information on a changing climate.
2. Click here or here for the latest news and information relating to water and climate change.

I have acknowledged the risks highlighted in this section.

10

The sections above detail all High and Medium risks from Aware[TM]. Selected Low risks are also detailed. Local conditions, however, can be highly variable, so if you have any concerns related to risks not detailed in this report, it is recommended that you investigate these further using more site-specific information or through discussions with the project designers.

HELP AND GLOSSARY:

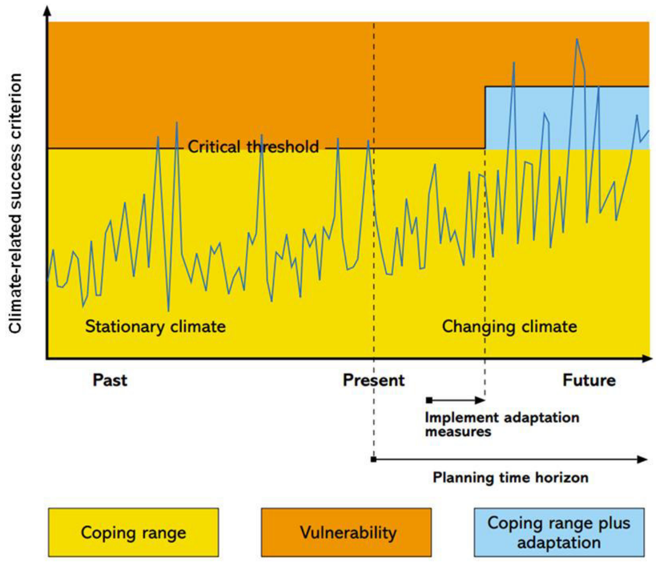
Model agreement and uncertainty:

Although climate models are constantly being improved, they are not good enough to predict future climate conditions with a degree of confidence which would allow precise adaptation decisions to be made. Outputs from different climate models often differ, presenting a range of possible climate futures to consider, and ultimately a wide range of possible actions to take. In Aware, climate projections are described as having potentially higher degree of uncertainty when less than 14 out of 16 GCMs agree on the direction and / or a pre-defined magnitude of change.

Even with improvements in climate modelling, uncertainties will remain. It is likely that not all the climate statistics of relevance to the design, planning and operations of a project's assets and infrastructure will be available from climate model outputs. The outputs are typically provided as long-term averages, e.g. changes in average monthly mean temperature or precipitation. However, decisions on asset integrity and safety may be based on short-term statistics or extreme values, such as the maximum expected 10 minute wind speed, or the 1-in-10 year rainfall event. In such cases, project designers or engineers should be working to identify climate-related thresholds for the project (see "Critical thresholds" section below) and evaluate whether existing climate trends are threatening to exceed them on an unacceptably frequent basis. Climate models can then be used to make sensible assumptions on potential changes to climate variables of relevance to the project or to obtain estimates of upper and lower bounds for the future which can be used to test the robustness of adaptation options.

The key objective in the face of uncertainty is therefore to define and implement design changes (adaptation options) which both provide a benefit in the current climate as well as resilience to the range of potential changes in future climate.

Critical thresholds:

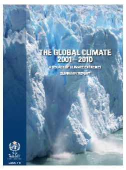
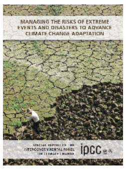
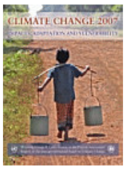


The relationship between a critical threshold and a climate change related success criterion for a project. [Source: Willows, R.I. and Connell, R.K. (Eds.) (2003). *Climate adaptation: Risk, uncertainty and decision-making*. UKCIP Technical Report, UKCIP, Oxford].

A key issue to consider when assessing and prioritising climate change risks is the critical thresholds or sensitivities for the operational, environmental and social performance of a project. Critical thresholds are the boundaries between ‘tolerable’ and ‘intolerable’ levels of risk. In the diagram above, it can be seen how acceptable breaches in a critical threshold in today’s climate may become more frequent and unacceptable in a future climate.

Climate change scenarios can be used to see if these thresholds are more likely to be exceeded in the future. The simplest example is the height of a flood defence. When water heights are above this threshold, the site will flood. The flood defence height is the horizontal line labelled ‘critical threshold’. Looking at the climate trend (in this case it would be sea level or the height of a river) – shown by the blue jagged line – it can be seen that the blue line has a gradual upward trend because of climate change. This means that the critical threshold is crossed more often in the future – because sea levels are rising and winter river flows may be getting larger. So, to cope with this change, adaptation is needed – in this case, one adaptation measure is to increase the height of the flood defence.

Further reading:

	Report detailing changes in global climate: The Global Climate 2001 - 2010 (PDF)
	IPCC report on climate-related disasters and opportunities for managing risks: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)
	IPCC report on impacts, adaptation and vulnerability: Working Group II Report "Impacts, Adaptation and Vulnerability"
	IFC report on climate-related risks material to financial institutions: Climate Risk and Financial Institutions. Challenges and Opportunities.

Aware data resolution:

The proprietary Aware data set operates at a resolution of 0.5 x 0.5 decimal degrees (approximately 50 km x 50 km at the equator). These proprietary data represent millions of global data points, compiled from environmental data and the latest scientific information on current climate / weather related hazards together with potential changes in the future. Future risk outcomes are based on projections data from the near- to mid-term time horizons (2020s or 2050s, depending on the hazard and its data availability).

Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were downscaled to a 0.5 degree grid.

[Meehl, G. A., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. F. B. Mitchell, R. J. Stouffer, and K. E. Taylor: The WCRP CMIP3 multi-model dataset: A new era in climate change research, Bulletin of the American Meteorological Society, 88, 1383-1394, 2007]

Aware data application:

In some instances Risk Topic ratings are only based on Aware data, including:
• Flood
• Permafrost
• Landslides

Country level risk ratings:

These are generated from the data points within a country's borders. For single locations, site-specific data are used, and for multiple locations or countries, composite data across the portfolio of locations are used.

Glossary of terms used in report

"Climate model projections agree": defined as more than 14 out of 16 GCMs agreeing on the magnitude (e.g. temperature warming of 2 °C) and / or direction of change (e.g. seasonal precipitation).
"Climate model projections do not agree": defined as 14 or fewer out of 16 GCMs agreeing on the magnitude (e.g. temperature warming of 2 °C) and / or direction of change (e.g. seasonal precipitation).
"Significant proportion": defined as at least 25% of locations when multiple locations are selected.
"Large proportion": defined as at least 75% of locations when multiple locations are selected.

The above thresholds are used as a means of providing a project-wide risk score where a project may be spread across multiple locations. This requires more than one individual location to be at risk to begin signifying whether there is a risk at the overall project level. However, it is always recommended that individual locations are analysed separately for more accurate, site-specific risk screening. The overall risk score for the project (high, medium or low) is based on a count of high risk topic scores. A project scores overall high risk if greater than or equal to 3 individual risk topics score high. A project scores overall medium risk if between 1 and 2 individual risk topics score high. A project scores overall low risk if none of the individual risk topics score high.

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