PROVINCIAL WATER SUPPLY AND SANITATION PROJECT

Project/loan number: 48158 - 002 - CAM

CLIMATE RISK AND VULNERABILITY ASSESSMENT

JUNE 2017

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Acronyms

ADB	Asian Development Bank
AFD	Agence Française de Développement
ARI	average return interval
CCSP	Climate Change Strategic Plan
CDIA	City Development Initiative for Asia
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CR-PRIP	Climate Resilience for the Provincial Road Improvement Project
CRVA	climate risk and vulnerability assessment
CSIRO CCAM	Conformal Cubic Atmospheric Model of the Commonwealth Scientific and Industrial Research Organisation
DCI	ductile cast iron
DDF	depth, duration, frequency
DIH	Provincial Department of Industry and Handicrafts
FRMI	Flood Risk Management Interface (of MPWT, Cambodia)
GCM	general circulation model
GEF	Global Environment Facility
GEV	generalized extreme value
GHG	greenhouse gas
GIS	geographic information system
GLO	generalized logic
IDF	intensity, duration, frequency
IPCC	Intergovernmental Panel on Climate Change
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Works and Transport
MRC	Mekong River Commission
MSQWEP	Multi-Source Quantile Weighted-Ensemble Precipitation
NPV	net present value
NSDP	National Strategic Development Plan
OECD	Organisation for Economic Co-operation and Development
PDSI	Palmer Drought Severity Index
PET	potential evapotranspiration
RAMS	road asset management system
RCM	regional climate model
RCP	Representative Concentration Pathway
RGC	Royal Government of Cambodia
SPEI	Standard Precipitation Evapotranspiration Index
SRES	special report on emissions scenarios
SRTM	Shuttle Radar Topographic Mission
UNFCCC	United Nations Framework Convention on Climate Change
WQ	water quality
WSS	water supply and sanitation
WTP	water treatment plant
WWTP	wastewater treatment plant

1. Executive Summary

1. An agreement was reached by MIH, MPWT and MEF on six (6) prioritized subprojects in four (4) towns. The Table 1-1 below summarizes the final outcome of the prioritization exercise:

Table 1-1 Final subproject selection

City	Water Supply	Wastewater	Septage
Battambang	X	X	
Kampong Cham	X		X
Sihanoukville		X	
Siem Reap		X (sewer rehabilitation)	

2. Climate change projections have been carried out for the four cities. The projections are based on Representative Concentration Pathway[1] (RCP)8.5 for the years 2030 and 2050. Rainfall data on a daily basis for 25 years was obtained from MOWRAM.

3. Flood risks have been assessed using the MPWT in house software Flood Risk Management Interface FRMI[2].

4. Projections show that the increase in intensity of rainfall during extreme weather events does not vary across the country.

5. The 1 in 10 year event by 2030 under RCP 8.5 will experience a 4 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 7% increase in 1 hour rainfall intensity.

6. The 1 in 100 year event by 2030 under RCP 8.5 will experience a 7 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 12% increase in 1 hour rainfall intensity.

7. The projected results show that by the year 2050 daily peak temperatures could reach 49.5°C. This would be a 1 in 100 year event. A more common scenario would be daily peak temperatures reaching 47°C which would be a 1 in 10 year event.

8. The highest probability of a severe drought occurring is 7.5% by the year 2050 in Battambang. This equates to a 1 in 13 year event. The highest probability of an extreme drought occurring is 4.29% by the year 2030 in Siem Reap. This equates to a 1 in 23 year event. The climate change risks for the cities and associated subproject components are given below.

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[1] Representative Concentration Pthways (RCPs) are models of distribution and concentration of four representative greenhouse gases, used for climate modelling and sanctioned by the Intergovernmental Panel on Climate Change (IPCC). RCPs supersede Emissions Scenarios previously adopted by IPCC

[2] Flood risk modelling software developed for the Ministry of Public Works and Transport, Cambodia that integrates meteorological and spatial input data to provide users with risk and cost information to guide decision making.

Table 1-2 Climate Change Risks

<table>
<tr><th>City</th><th>Water Supply</th><th>Wastewater</th><th>Septage</th><th>Climate Change Risk</th></tr>
<tr><td>Battambang</td><td>X</td><td colspan="2"></td><td>High</td></tr>
<tr><td>Battambang</td><td></td><td colspan="2">X</td><td>Moderate</td></tr>
<tr><td>Kampong Cham</td><td>X</td><td></td><td></td><td>Moderate</td></tr>
<tr><td>Kampong Cham</td><td></td><td></td><td>X</td><td>Low</td></tr>
<tr><td>Sihanoukville</td><td></td><td colspan="2">X</td><td>Moderate</td></tr>
<tr><td>Siem Reap</td><td></td><td colspan="2">X (sewer rehab)</td><td>Low</td></tr>
</table>

2. Introduction

2.1. The Project

9. The project comprises the following components :

- Battambang: Water Supply + Wastewater and Sanitation
- Kampong Cham: Water Supply + Septage Treatment
- Sihanoukville: Wastewater and Sanitation
- Siem Reap: Wastewater/ Drainage (trunk replacement)

Figure 2-1 Location of the study sites

An agreement was reached by MIH, MPWT and MEF on July 14, 2016, and subsequently shared with CDIA, ADB and AFD, that Preliminary Engineering Design and costing work will be carried out for six (6) prioritized subprojects in four (4) towns. The Table below summarizes the final outcome of the prioritization exercise:

Table 2-1 Final subproject selection

City	Water Supply	Wastewater	Septage
Battambang	X	X	
Kampong Cham	X		X
Sihanoukville		X	
Siem Reap		X (sewer rehabilitation)	

10. Preliminary cost estimates for these six (6) subprojects in the four (4) towns presented at the DFR Workshop and subsequently updated are presented in the table below.

Table 2-2 Summary of Cost estimates for the 6 selected subprojects (USD Millions)

Town	Water Supply	Sanitation	Total
Battambang	34.9 M	10.6 M	45.5 M
Kampong Cham	12.7 M	0.79 M	13.5 M
Sihanoukville		14.6 M	14.6 M
Siem Reap		15.9 M	15.9 M
Total	**47.6 M**	**41.9 M**	**89.5 M**

2.2. ADB's Approach to Water Supply and Sanitation

11. Water supply and sanitation is an important sector of investment supported by the Asian Development Bank (ADB). For the period 2006–2014, ADB-approved investments in water supply and sanitation amounted to nearly $10 billion or around 7% of ADB's lending portfolio.[3]

12. The provision of water supply and sanitation services is particularly vulnerable to projected changes in climate conditions (temperature and precipitation among others), in the frequency and intensity of extreme weather events, as well as in the projected rise in sea level and the intensification of storm surges[4]. With respect to Cambodia this can lead to the following effects:

- In coastal areas, sea-level rise and the increased intensity of storm surges may lead to saline intrusion into groundwater aquifers as well as surface water.
- Warmer temperatures may increase evaporation from surface waters and reduce water supply availability.
- Higher water temperatures may induce a greater presence of existing or new microorganisms which water and wastewater treatment facilities may find increasingly difficult and costly to treat to required standards.
- Water supply and wastewater treatment infrastructure may experience a greater risk of damage as a result of more frequent and/or more intense extreme weather events, floods, and drought.

13. These possible impacts may have significant consequences for water and sanitation projects.[5]

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[3] Guidelines For Climate Proofing Investment in the Water Sector : Water Supply And Sanitation, ADB 2016

[4] Sector Briefing on Climate Change Impacts and Adaptation: Water Supply And Sanitation ADB, January 2012

[5] Climate Change and Water Governance in Cambodia, Challenge and Perspectives for Water Security and Climate Change in Selected Catchments, Cambodia, Cambodia Development Resource Institute, Phnom Penh, December 2015.

2.3. ADB's Approach to Climate Change

14. From 2011 to 2015, ADB approved over $15.5 billion of climate financing. In 2016 ADB approved a further $3.7 billion in climate finance investments representing a 42% increase over 2015.[6]

15. ADB have published many guidelines on climate change and these have been referred to in the preparation of this report. These include :

- Sector Briefing on Climate Change Impacts and Adaptation: Water Supply And Sanitation ADB, January 2012.
- Guidelines For Climate Proofing Investment in the Water Sector : Water Supply And Sanitation, ADB 2016

2.1. Cambodia Approach to Climate Change

16. In addition to ADB publications Cambodia has produced several guides on Climate Change and they have been referenced in this report. They include:

- Climate Change and Water Governance in Cambodia, Challenge and Perspectives for Water Security and Climate Change in Selected Catchments, Cambodia, Cambodia Development Resource Institute, Phnom Penh, December 2015.
- Climate Change Strategic Plan for Water Resources and Meteorology (2013-2017), Ministry of Water Resources and Meteorology, Phnom Penh, 2012

17. Further references are given where appropriate in the report.

[6] ADB's Focus on Climate Change and Disaster Risk Management, WWW.AB.ORG, 2017

3. Design Overview

3.1. Battambang Water Supply

3.1.1. Project objective

18. The Battambang water supply will supplement the existing system and support Royal Government of Cambodia (RGC) policy in providing potable water to all people by 2025. This subproject aims at filling the gap between the existing capacity, including the JICA Phase II service area, and the future demand within the proposed extended service areas (see Figure 3-1). The water supply scheme will meet the needs for the next 20 years (2020-2040) of the proposed population of 90-100% of persons in Battambang town and 80-90% of communities near to the town.

3.1.2. Project Components

19. The main components are:

- An intake with a capacity of 50,000m^3/d to take raw water from the Sangké River
- A 5 km transmission line from the intake to the water treatment plant (WTP)
- Under Phase 1 a WTP with a capacity of 50,000m^3/d
- 120km distribution network.
- Some 1,700 additional connections initially were planned and 1,400 new connections annually thereafter from 2017 onwards
- Under Phase 2 commencing in 2026 construction of a WTP of at least 80,000 m^3/d to meet the 2040 water demand
- A total distribution network of 240km
- Population by 2040 to be 75,000 families or 360,000 people of which 51% are women.
- Estimated cost is US$ 34.9 million.
- Phase 1 implemented 2018-2020, construction period of 2-2.5 years.

3.1.3. Treatment Process

20. A conventional treatment process will be followed of coagulation – flocculation - sedimentation - rapid sand filtration – chlorination – clear water storage. This is used at the vast majority of plants in Cambodia and was agreed by the MIH/DIH. The service building, pump station, chemical/workshop building, and other items common to both phases are included in Phase 1 construction.

3.1.4. Raw Water Intake

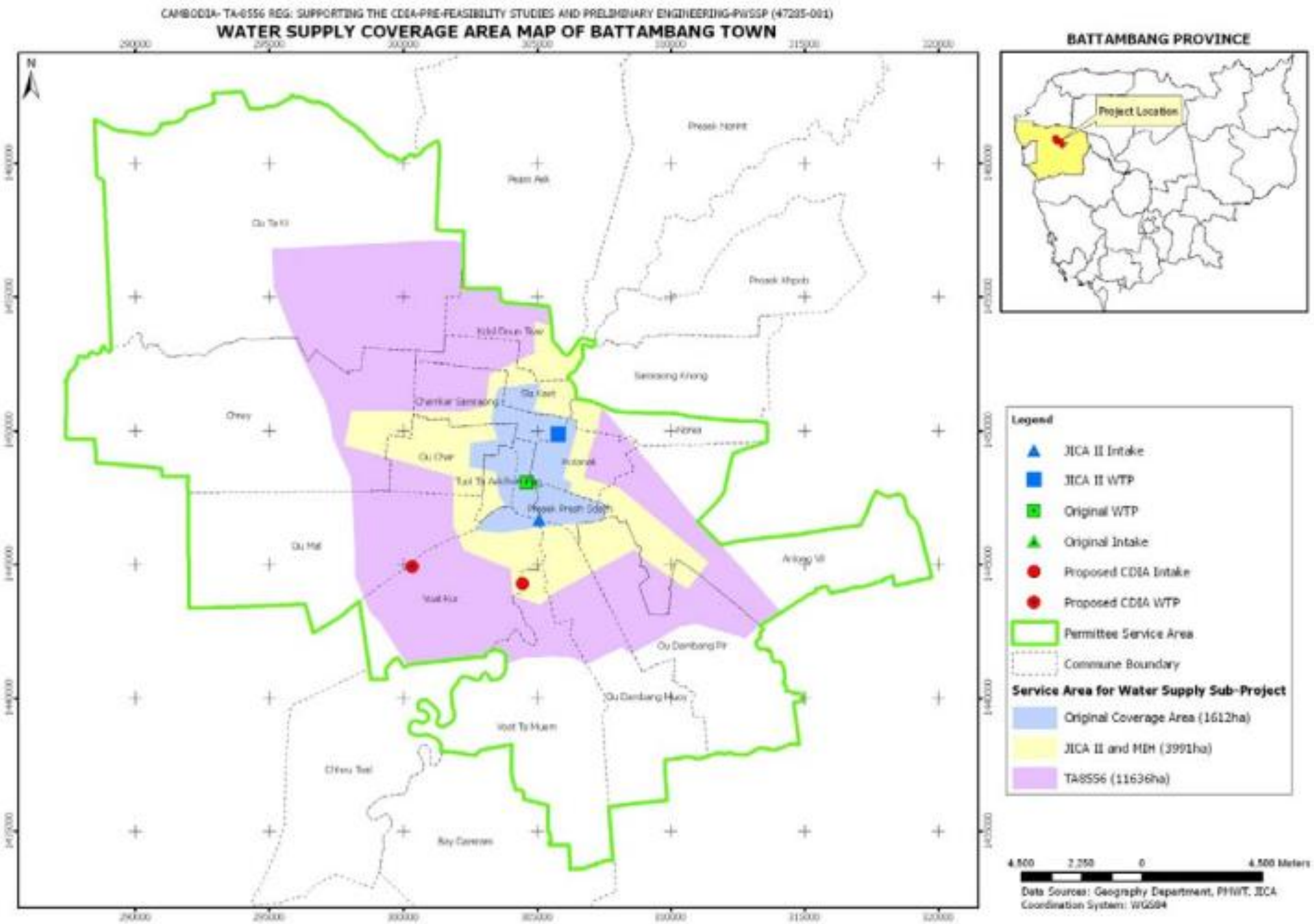
21. The raw water intake will be located on the Sangké River. Land commitment for the WTP is confirmed but commitment for the water intake is being secured.

3.1.5. Permits

22. There are no permits required, except a water source allocation MOU, to be secured from the MoWRM to have the raw water available from the Sangké River in an amount up to 50,000m^3/d for 2025.

23. A letter has been sent from MIH to MOWRAM requesting confirmation of this supply. So far no formal confirmation has been received.

Figure 3-1 Battambang Water Supply subproject coverage area and project facilities location



3.1.6. Summary Proposed Facilities

24. A summary of the project Phase 1 is given below.

Table 3-1 Phase 1 (Year 2020-2025) for Battambang

Raw Water	
Water Source	Sangké River; Battambang HWL=15.57 masl, LWL=4.81 masl
Intake	
Capacity	50,000 m^3/d
Pump	• Total pump capacity: 2,083 m^3/h or 579 L/second • Four pumps (vertical turbine pump) will be installed: 3 duty and 1 standby • Total head 35 m
Raw Water Transmission	
Raw water pipe	Diameter : 710 mm Length : 5 km
Water Treatment Plant (WTP)	
Capacity	50,000 m^3/d
Treatment facilities	• Receiving well: Reinforced concrete; 2 units • Rapid Mixing: Reinforced Concrete Structure with gravitational force mixing using a weir; 2 units • Flocculation: Vertical channel baffled flocculator; 8 units • Sedimentation: Reinforced Concrete Structure, Horizontal- Flow Sedimentation Basin; 8 units; • Filtration: Reinforced Concrete Structure; 12 units; Underdrain System: Porous Filter Bed Method; Filtration Rate: V=126.6 m/day (120-150 m/day)
	• Flow Control: Lower Part Control Method • Backwash Method: Simultaneous Backwash Method by Air and Water • Clearwater Reservoir: Reinforced Concrete Structure using Flat Slab Structure; Effective Volume: 12,800 m^3, Effective Water Depth: H= 4.30, Detention Time: T= 3 hours
Booster pump at WTP	• Total pump capacity: 3,192 m^3/h or 887 L/s • Four booster pump will be installed: 3 on-duty and 1 standby • Total head 26m
Distribution Networks	
Pipe network	120 km including 109 km of mains and 11km for connection of secondary and tertiary road houses
Construction Plan	2018-2020
Cost Estimates	Phases 1 and 2 : $34,899,700.

3.1.7. Cost Estimate

25. The preliminary cost estimate for Phases 1 and 2 of the proposed subproject is $**34,899,700.**

3.2. Battambang Sanitation

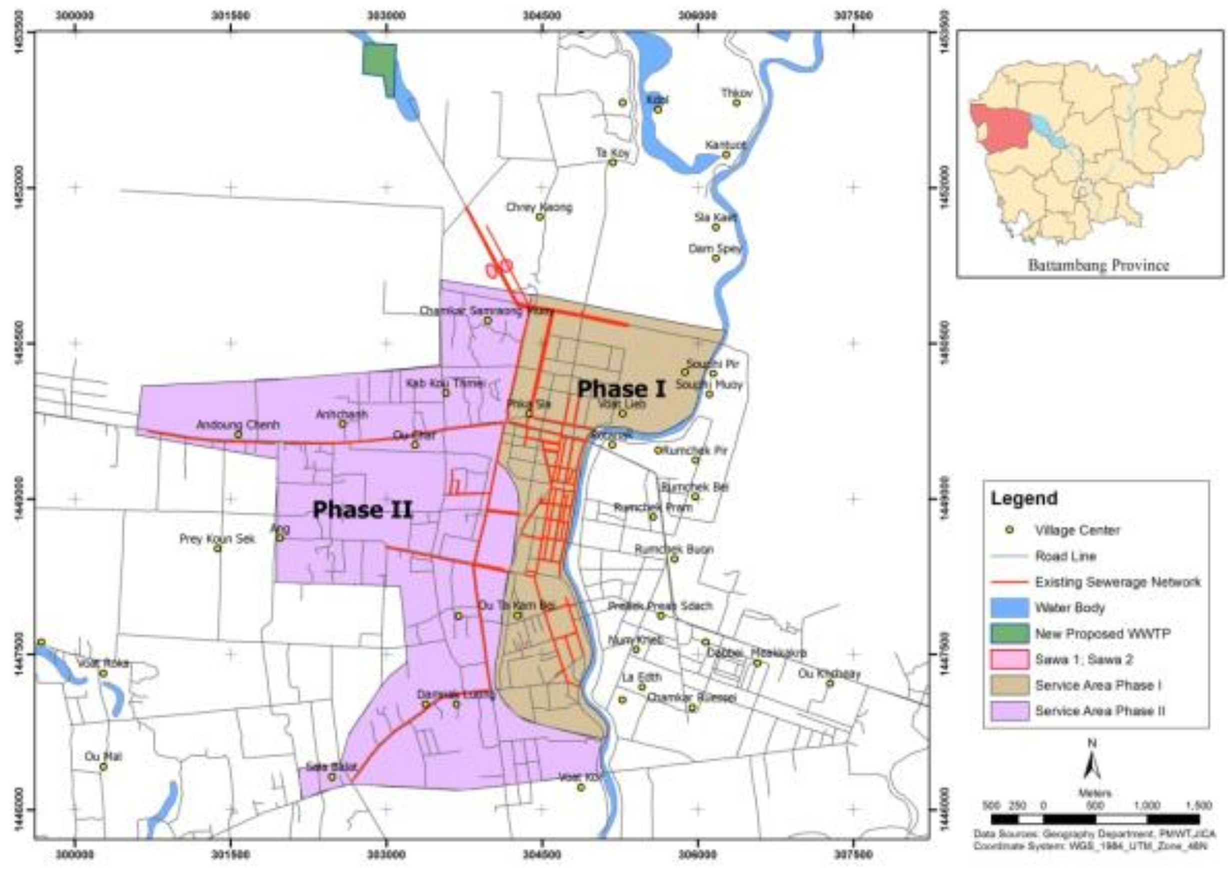
3.2.1. Project objective

26. The Battambang wastewater project will provide a new separated sewer network in priority areas and construct a new Waste Water Treatment Plant (WWTP). Waste water treatment for the wider urban area has been divided into two phases with the first phase addressing the main populated areas needs up to 2040.

27. The existing SAWA funded WWTP on a 5.8ha site is to be decommissioned, and a nearby new 6.6ha site developed with a trickling filter based WWTP with a pre-settlement (anaerobic pond) with a design capacity of 11,645m^3/d. A proposed Japan Fund for the Joint Crediting Mechanism (JFJCM) grant will provide support for the incremental cost and capacity development of advanced and energy efficient trickle filters for the WWTP, to reduce carbon emissions This will provide adequate treatment for Phase 1 to 2040 and provide space for expansion for Phase 2 at a later date.

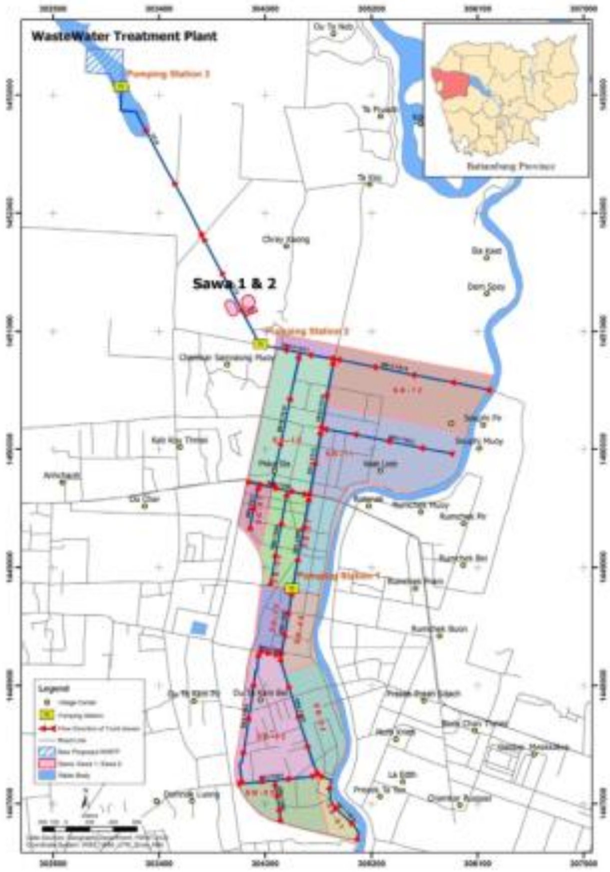
28. The area encompassed by Phase 1 includes all of the densely populated areas of the city centre and most of the intermediately populated areas just outside of the centre. Figure 3-2 shows the Phase 1 and 2 areas of service.

Figure 3-2 Phase 1 & 2 service area of Battambang sanitation project



29. The location of the pumping station and trunk sewers in Phase 1 is shown below.

Figure 3-3 Location of pumping station and trunk sewers in Phase 1 for Battambang project



3.2.2. Project Components Shortfalls and Solutions

30. The table below summarises the current situation, shortfalls in service, and the solutions to these shortfalls offered under the proposed subproject.

Table 3-2 Current and Proposed situation for sanitation in West Battambang

Current situation	Shortfall	Proposed
Main colonial-era city centre area served	Very limited service area	Two phases of development: city centre area followed by wider urban area.
Combined system	Very large flows during wet season, with combined flows flooding town and entering environment untreated.	A separated system is proposed
Trunk sewers sized for city centre only, with restrictions in some areas.	Insufficient or wrongly configured trunk sewers	New main trunk sewers

Old pumps between anaerobic ponds and facultative ponds are limiting capacity of existing WWTP	Pumps operating at 450m^3/d instead of designed 1,000m^3/d	Decommissioning of existing 5.8ha WWTP lagoon site.
WWTP designed for 1,000m^3/d which was intended to serve 15,000 people or 3,125 households. Now reduced to 450m^3/d serving 1,400 households	11,645m^3/d required for Phase 1; 20,694m^3/d required for full city to 2040	Decommissioning of existing 5.8ha WWTP lagoon site. Development of conventional trickling filters for proposed new 6.6ha site, staged for 2 Phases. Development of aerated lagoons if a minimum of 15ha becomes available. Phase 1 will serve 40,311 people on commissioning in 2020 and 57,803 by 2040.
Current WWTP land was fully utilized by 1994 project	No further reserved land for expansion	A further 6.6ha site is approved by District Governor
Septic tank septage disposed of to agricultural land	No septage management	Each settlement pond to have septage disposal bay with concrete apron and service water for cleaning.
There are 7 nos private septage vacuum trucks operating	No regulation of private septage trucks. No DPT vacuum truck.	Provide one 6m^3 septage vacuum truck for DPWT. Develop regulation of private septage trucks under capacity building.
No sludge removal or drying facility	No equipment or space on site	Include sludge drying beds plus supply of dewatering container and compact excavator.

3.2.3. WWTP Options

31. Two options have been recommended, dependent on final land availability.

3.2.3.1. Aerated Lagoons

32. The current "SAWA" WWTP on 5.8ha would be decommissioned. With a 15ha site all separated wastewater to year 2040 could be treated using aerated lagoons. The WWTP would consist of two separable trains of lagoons, each train being two anaerobic lagoons, one facultative lagoon and one maturation lagoon. The extension to land already acquired would need to be of an appropriate shape to accommodate these lagoon trains. The anaerobic lagoons would have solar aerators specifically designed for these lagoons installed, which disturb only the upper 20-30cm of water and reduce odours and break the scum layer without producing aerosols. The size of the lagoons is shown below.

Table 3-3 Sizes of selected aerated lagoons

Process	No. ponds	Length	Width	Depth	Area (ha)
Anaerobic	4	40	25	4	0.193
Facultative	2	157	57	1.75	1.499
Maturation	2	348	120	1.5	8.352
				Total	10.044

33. The remaining 5.6ha of the required 15ha site will be taken up with site roads, sludge drying beds, office, store, car parking and bunds.

3.2.3.2. Conventional Trickling Filters

34. Should an additional 8.4ha immediately adjacent to the ready-acquired 6.6ha not become available in the near future, then the recommendation is for sedimentation ponds and conventional trickling filters on the same 6.6ha site.

3.2.4. Septage Collection

35. Only 17% of the central city area is currently connected to the wastewater treatment plant so the majority of urban properties are reliant on either a septic tank or concrete holding/soakaway tank (pour flush pit latrine). There is no record of numbers, volumes or condition of septic tanks in the city. Demand from householders to have their septic tanks de-sludged is based on when they block or cause a smell nuisance rather than by preventative maintenance or periodic checking of sludge depth. Septage is currently collected by 7 private vacuum trucks who disposed of it to agricultural land on the edges of the town.

36. Private septage collectors will require regulating once the new WWTP is opened, both to ensure that septage is co-treated in the WWTP and that private operators pay for this service. It is suggested that all septage collection operators require a license to operate in the urban area, and that a condition of this licence is that all septage is disposed of to the WWTP.

3.2.5. Septage Treatment

37. If the new WWTP proposal option of provision of trickling filters are taken, co-treatment of septage is recommended in the upstream anaerobic ponds. Septage will be collected and treated in the anaerobic lagoons prior to the trickling filter based WWTP. Sludge will be removed and thickened by the sludge dewatering container and then disposed of as cover for the nearby landfill.

3.2.6. Cost estimate

38. The cost estimate for this wastewater and sludge co-treatment subproject is $10,646,687.

3.3. Kampong Cham Water Supply

3.3.1. Project Objective

39. The Kampong Cham water supply will supplement the existing system and support RGC's policy in providing potable water to all people by 2025. This subproject aims at filling the gap between the existing capacity, including the JICA Phase II service area, and the future demand within the proposed extended service areas. (See Figure 3-4) The water supply scheme will meet the needs for the next 20 years (2020-2040) of the proposed population of 90-100% of Kampong Cham and 85% of the three communities nearby the town.

3.3.2. Project Components

40. The main project components are:

- A water intake with a capacity of 11,600m^3/d to draw raw water from the Mekong River
- A 4km transmission line to the WTP.
- A new WTP of at least 26,100 m^3/d to provide sufficient capacity until 2040
- 80km of distribution network
- Expanded service area of 35km^2 by 2025.
- Served population (to 2040): approximately of 31,182 families with total 140,318 persons, out of which 71,562 are women (50.9%).
- A 2.5 year contract period from 2018 to 2020.

3.3.3. Treatment Process

41. A conventional treatment process will be followed of coagulation – flocculation - sedimentation - rapid sand filtration – chlorination – clear water storage). This is used at the vast majority of plants in Cambodia and was agreed by the MIH/DIH.

42. The location of the proposed WTP is shown in figure 3-5. The service building, pump station, chemical/workshop building, and other items common to both phases are included in Phase 1 construction.

3.3.4. Raw Water Intake

43. A raw water intake will be located on the Mekong River extracting up to 11,600m^3/d by 2025.

3.3.5. Permits

44. There are no permits required, except a water source allocation MOU, to be secured from the MoWRM for the raw water extraction from the Mekong River to the proposed WTP. Land commitment on the WTP and the Intake is confirmed.

Figure 3-4 Kampong Cham WS subproject coverage area

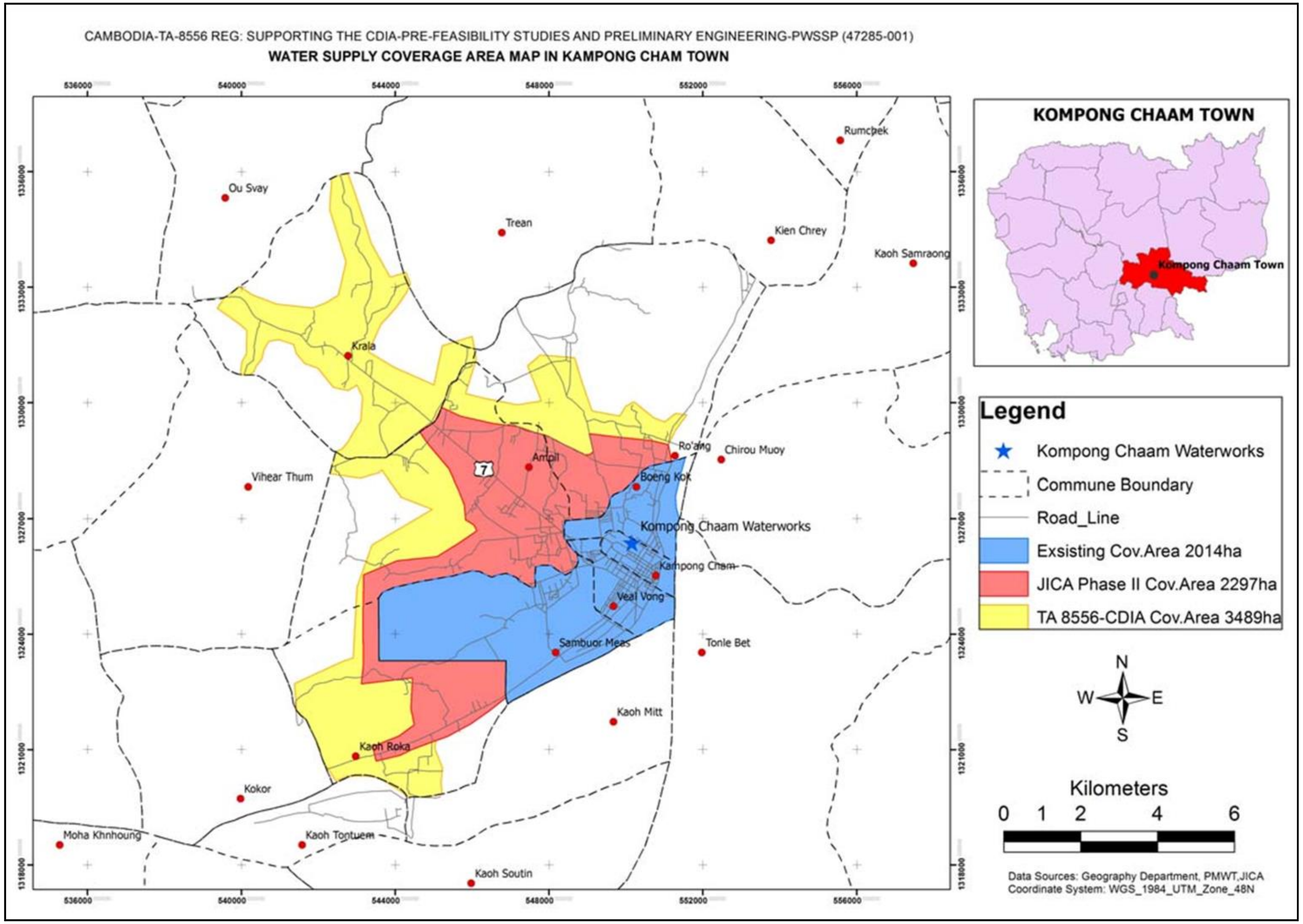
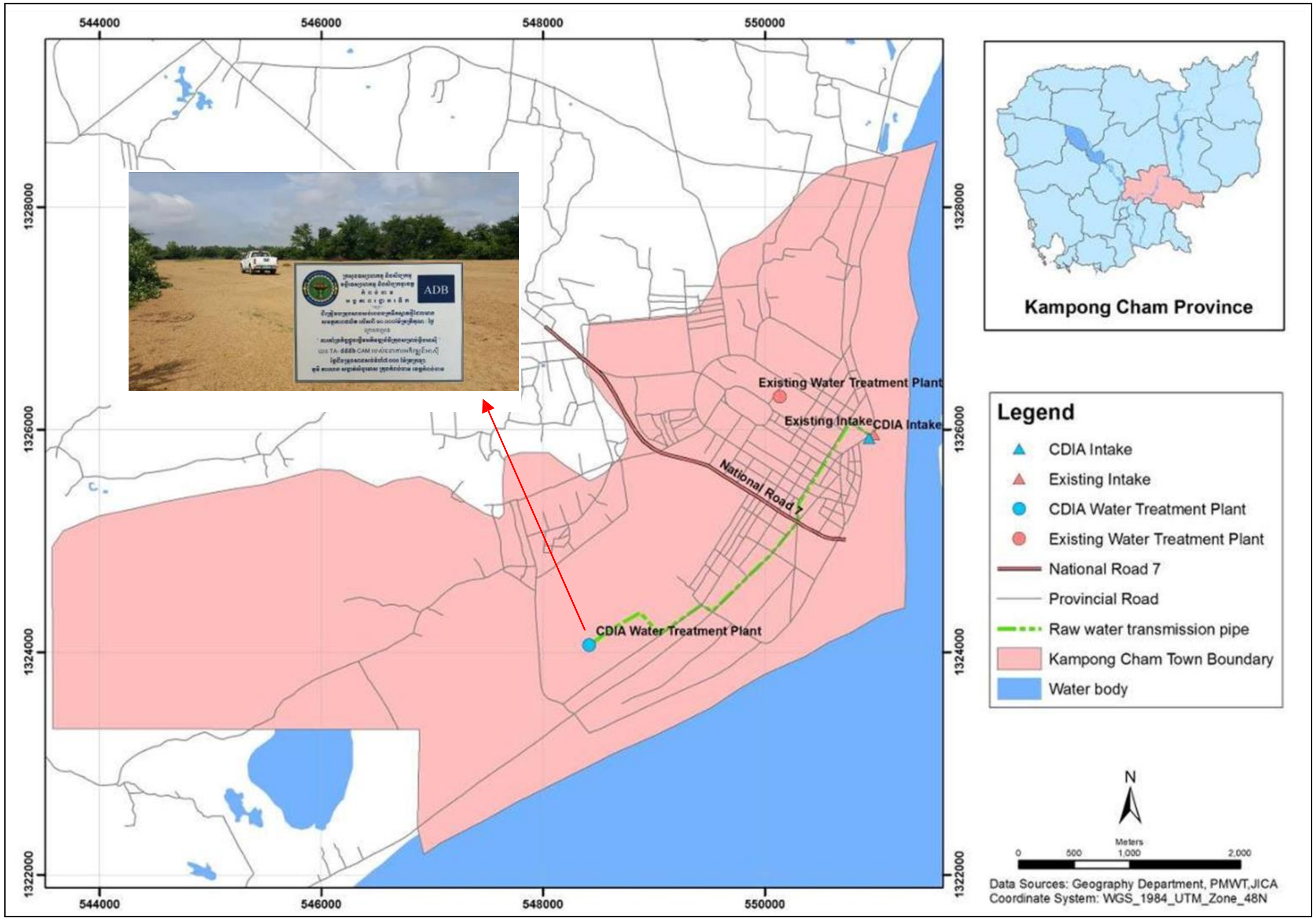


Figure 3-5 Kampong Cham project facilities location



3.3.6. Summary Proposed Facilities

45. A summary of the project Phase 1 is given below.

Table 3-4 Outline of Facilities for Kampong Cham in Phase 1 (2020-2025)

Raw Water	
Water source	Mekong river; HWL=15.18 m, LWL=0.63 m
Intake	
Capacity	11,600 m^3/d
Pump	• Total pump capacity: 135 L/s • Three pumps (vertical turbine pump) will be installed: 1 in duty and 1 standby • Total head 41m
Raw Water Transmission	
Raw water pipe	Diameter : 350 mm ; Length : 4 km
Water Treatment Plant (WTP)	
Capacity	11,600 m^3/d
Booster pump at WTP	• Total pump capacity: 227 L/s • Three Booster pump will be installed: 2 in duty and 1 standby • Total head 36m (following pump selection)
Treatment facilities	• Rapid Mixing • Flocculation • Sedimentation • Filtration • Disinfection
Distribution Networks	
Pipe network	52 Km main pipes + 28 km of smaller pipes
Booster pump along the distribution network	• Total pump capacity: 136 L/s • Three Booster pump will be installed: 2 in duty and 1 standby with capacity 68 L/s each pump • Total head 29m (following pump selection)
Construction plan	2018-2020
Cost Estimates	**$12,765,500**

3.3.7. Cost Estimate

46. The preliminary cost estimates for Phase 1 is $12,765,500.

3.4. Kampong Cham Septage

3.4.1. Project Objective

47. The Kampong Cham septage subproject is proposed to rectify the poor situation in Kampong Cham with respect to septage collection and disposal from existing septic tanks.

3.4.2. Septage collection

48. The coverage of septic tanks in central Kampong Cham, whilst numbers are not known, is thought to be fairly low, and the size, age and condition of septic tanks is unknown. Many households, even in the central city, have concrete ring soak away tanks which do not provide any treatment and pollute the water table. Septage collection, in common with other towns in Cambodia, is currently mainly carried out by the private sector. There are currently only a small number of vacuum truck operators in Kampong Cham, but with the capacity building and public awareness proposed under the subproject this should increase. As operators become busier, carrying more loads per day, the incentive to invest further in another truck will arise, in addition to more interest generated for more business people to become involved in the sector.

3.4.3. Project Components

49. The project will obtain suitable land and construct a 2,400m^3 treatment facility, including two facultative lagoons in parallel. Once septage is sufficiently dried for handling, the treated sludge can be removed from the lagoon using a compact excavator and truck, and either dewatered further using a dewatering container, deposited into sludge drying beds, or carried directly to landfill for disposal. The figure 3-6 below shows the currently proposed location for the facility.

50. The subproject will supply equipment to the DPWT for use with the septage treatment plant including :

- A 6m^3 vacuum truck
- Dewatering container (basic model)
- Compacting excavator

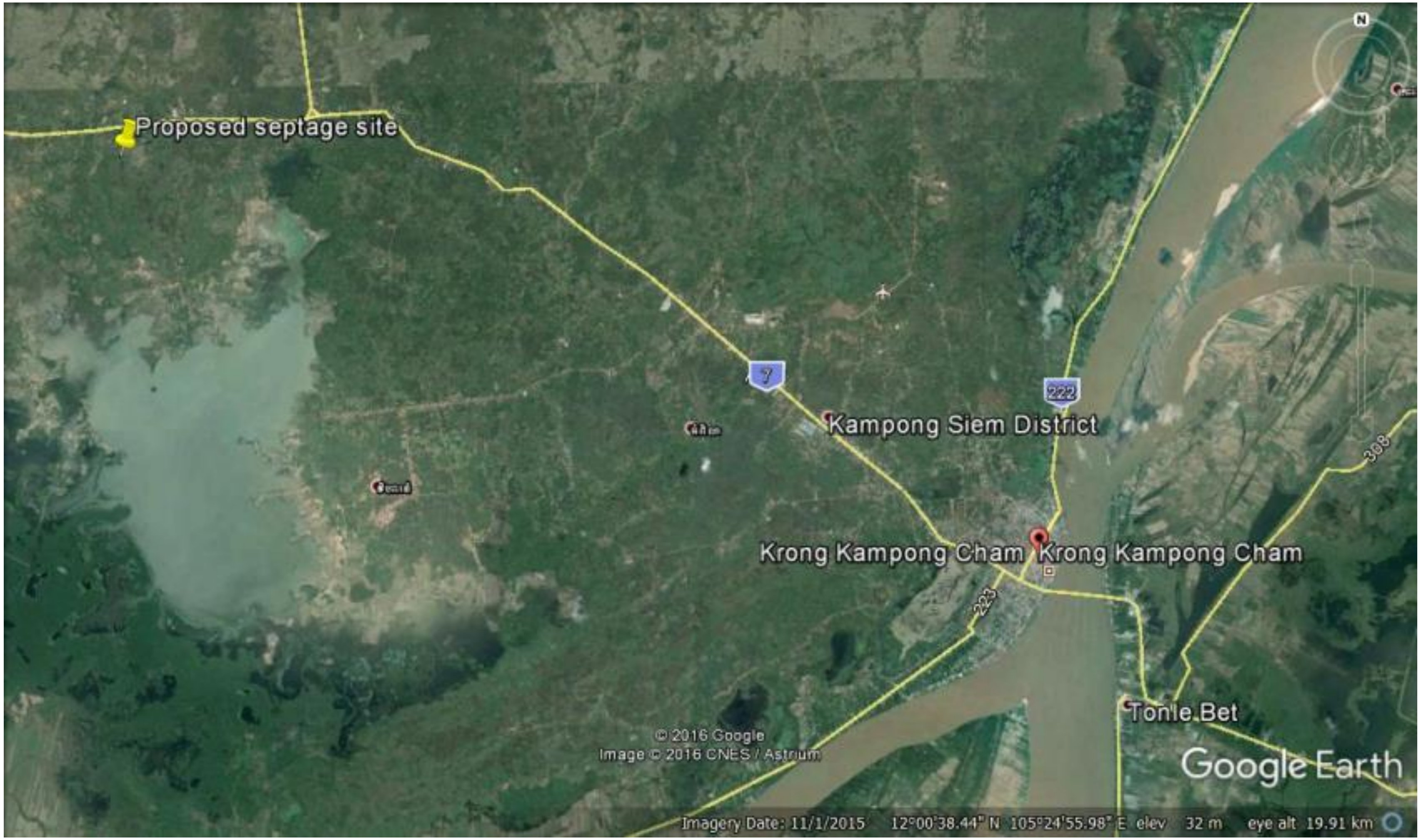
51. The subproject will also include capacity building for DPWT and private vacuum truck operators and a public awareness campaign aimed at increased understanding of septic tanks and the need for maintenance.

52. Capacity building is proposed for both septage treatment facility operators (DPWT staff) and the private sector. For the sustainability of the septage treatment facility it is vital to have both the support of the private vacuum truck operators through licensing and the increased awareness of the public in having their septic tanks emptied.

3.4.1. Cost estimates

53. The cost estimate for the sludge treatment subproject is US$790,000.

Figure 3-6 Proposed location for septage treatment facility at Kampong Cham



3.5. Sihanoukville Sanitation

3.5.1. Project Objective

54. The Sihanoukville wastewater subproject will address priority areas by constructing a separated sewer network, installing free domestic connections, and upgrading the existing WWTP to increase capacity. The upgrade of the current WWTP is limited to the current land footprint as no more land is available and several options for increasing wastewater treatment capacity have been discussed.

3.5.1. Project Components

3.5.1.1. Shortfalls in Service and Remedies

55. Table 3-5 summarises the current situation, shortfalls in service, and the solutions to these shortfalls offered under the proposed subproject.

Table 3-5 Current and Proposed situation for sanitation in Sihanoukville

Current	Shortfall	Proposed
Main city centre area served	Beach tourism areas and rest of city not served. Areas that could be connected without pumping only were considered.	4 main beach areas plus main urban centre to north west of existing service area to be connected
Only 1,767 of 3,368 (52%) properties proposed under first project have been connected to date	Free connections were not included under first project	Free connections for remainder of 3,368 properties under first project service area, plus growth to 2020 for this service area (1,707 properties), plus 5 new service areas. Total new connections 8,295.
Trunk sewers sized for city centre only	Existing trunk sewers cannot be used for proposed extended service area	New trunk sewers proposed in parallel with existing ones to maintain service during construction
No pump stations. The part of the city centre forming the original service area was defined by the areas that could be served by gravity flow.	Large tracts of the city not connected due to pumping requirements.	Three new pump stations in the city and one each on Occheuteal and Otres beaches.
WWTP limited to 6,900m^3/d which was intended for 5,900m^3/d to serve 3,368 households plus a 1,000m^3/d allowance for effluent from Cambrew.	In reality approx. 3,000m3/d used by 1,767 households and the remaining 3,900m^3/d (or more) from Cambrew.	Upgrade of WWTP by mixing/aeration or other methods can increase capacity. Aeration alone can increase capacity up to 250% to meet 2040 demands for proposed new service areas. Trickling filters, oxidation ditches and UASB have also been considered.
Current WWTP land was intended for expansion by 2020 under original design	Land no longer available	WWTP expansion is limited to current site.

Beaches were intended to each have their own localised WWTP under original design	Land no longer available	WWTP expansion is limited to current site.
1 anaerobic pond full of sludge and other 3 half full	No portable sludge pump, no willingness to desludge manually, limited access into ponds.	Purchase of suitable portable sludge pumps with long intakes. Desludging under proposed project with improved access and equipment supply (bobcat)
No designed sludge drying bays.	No proper sludge drying. No sludge	Supply of simple containerised sludge

3.5.1.2. Septage Treatment

56. Septage in Sihanoukville, where collected, is treated in the anaerobic lagoons of the WWTP.

Table 3-6 Current and Proposed situation for septage treatment in Sihanoukville

Current	Shortfall	Proposed
Treated sludge currently dumped at side of lagoons as very limited space.	Disposal or re-use.	Dewatering. Disposal to landfill.
Septic tank septage disposed of to anaerobic ponds in adhoc manner	Operation not controlled and not clean	Each anaerobic pond to have septage disposal bay with concrete apron and service water for cleaning.
1 DPWT 6m^3 septage truck plus one 4m^3 private truck	Limited number of trucks for relatively large population and number of hotels	Provide one 6m^3 further septage vacuum truck for DPWT
Limited capacity in WW treatment & operation	Small number of expert staff	Capacity building for all DPWT staff
Low level of public awareness on wastewater	Septic tanks not maintained, some leaking, too small etc	Public awareness campaign through various media.

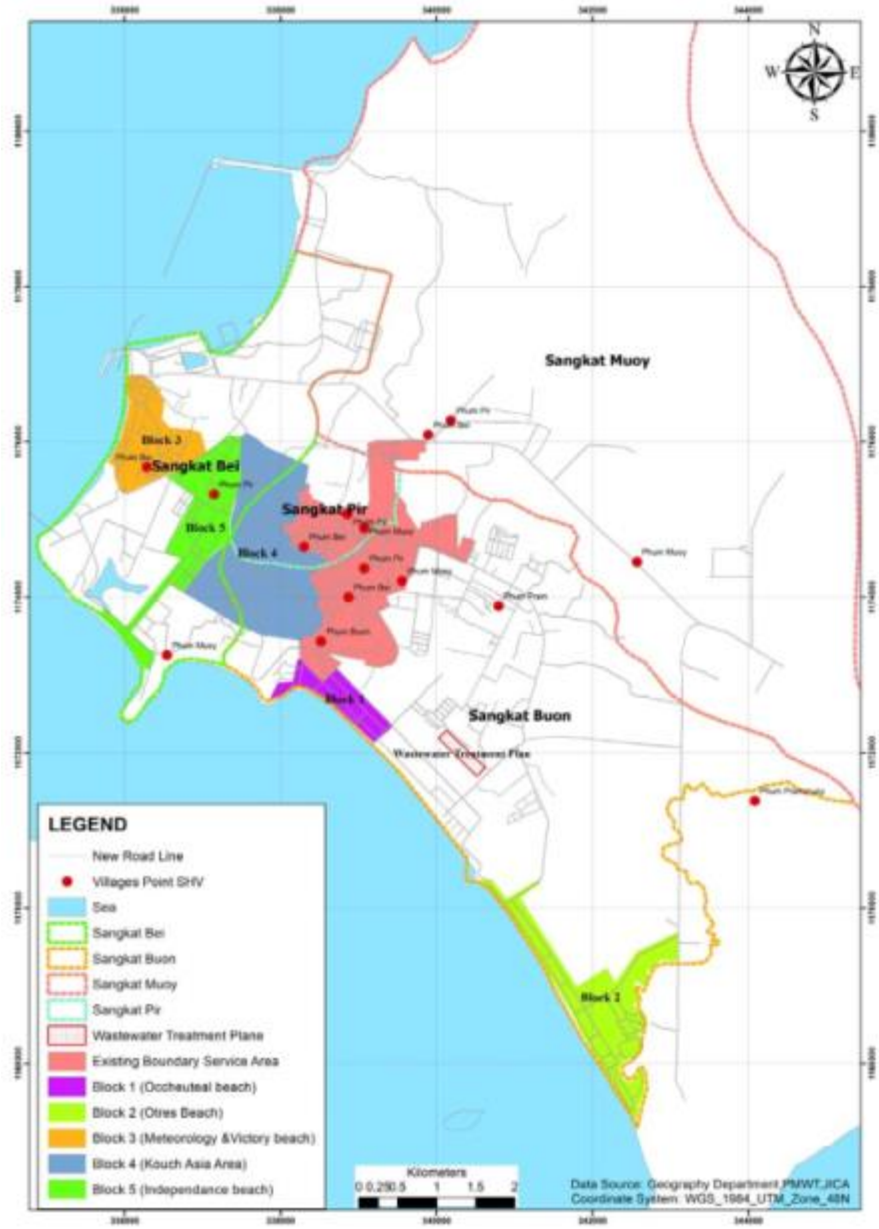
57. It is proposed that sludge will be removed and thickened by the sludge dewatering container and then disposed of as cover for the proposed landfill.

3.5.1.3. Proposed extension of coverage area

58. The proposed new service areas (“Blocks”) are:

- Ocheuteal beach (B1)
- Otres beach (B2)
- Victory Beach and Hill (B3)
- Kanpenh/Kouch Asia/Borey Kampor St/part of Ekkareach Rd/ north of Ekkareach Rd (B4)
- Independence beach (B5)

Figure 3-7 Existing and proposed service areas for Sihanoukville



3.5.1.4. Trunk sewer network overview

59. Trunk sewers have been designed for each proposed new area with wastewater from Victory Beach(B3), Kampenh Village/Kuch Asia(B4) and Independence Beach (B5) being delivered from the west to the beginning of a new 1200mm main trunk sewer starting at the Golden Lion roundabout, and Otres Beach(B2) and Occheuteal Beach(B1) being pumped separately from the east directly to the WWTP. The trunk sewer network is illustrated in the figure below.

Figure 3-8 Trunk sewer network overview

3.5.1.5. Pump Stations for Sihanoukville sewer system

60. In B-05 block (Independence beach area), there are two alternative proposed locations for the pump station, one on the road at a low point where surface water drains into the north east corner of the natural lake Boeng Preak Tub, and the other at the beach. The first option is the topographical preference but it might be difficult to acquire the land for pump station construction. The second option on public land at the beach is slightly higher but is much more

straightforward in terms of land availability. The locations of the pumping stations is illustrated in the figure below.

Figure 3-9 Location of pumping station and route of pumping main

3.5.1.6. Capacity increase by solar aerators

61. The WWTP recommendation has been split into two stages, one for the medium term to serve the areas that are currently developed with a significant population density. These areas are covered by the current and 5 proposed new sub-catchments. A longer term option is proposed that addresses future development areas outside of the 6 already covered areas along with further urban industrial development along NR#4.

62. In the short to medium term, during which the 5 prioritised new service areas will be connected to the separated wastewater system, it is proposed that significant changes to the current wastewater treatment regime in order to increase the capacity of the WWTP are minimised, whilst ensuring that any technology changes introduced are energy efficient.

63. As the current system, after 8 years of operation, has just surpassed 50% of the originally intended connections from the 2002 design, and as there are still clearly challenges with

providing adequate O&M to the plant (sludge drying and handling, influent and effluent quality and volume monitoring), it is recommended that floating solar powered mixers be used to increase the capacity of the current WWTP to between 200-300% of the current maximum. These mixers are stand-alone and, whilst more expensive than conventional mixers, use more advanced technology to offer significant lifetime power cost savings, and offer a very low carbon footprint. The solar mixers will also have the option to be run from mains power during periods of lower sunlight or during maintenance of solar panels.

64. Once the proposed 5 priority sub-catchments are served, there will be very few developed areas in Sihanoukville that will not be covered by the WW system for the short to medium term. In the longer term, beyond 2040, when further areas of the wider urban area which are currently sparsely populated become developed, it is proposed to employ conventional trickling filters.

3.5.1.7. Septage Collection and Treatment

65. Only 52% of the central city area is currently connected to the wastewater treatment plant and this is less than 15% of the total number of households in the city. The majority of urban properties are reliant on either a septic tank or concrete holding/soak away tank (pour flush pit latrine).

66. Septage in Sihanoukville is currently collected by only 2 vacuum trucks, one of $6m^3$ owned by DPWT and one privately owned truck of $4m^3$. Neither are fully employed. Demand from householders to have their septic tanks de-sludged is based on when they block or cause a smell nuisance rather than by preventative maintenance or periodic checking of sludge depth.

67. There is no record of numbers, volumes or condition of septic tanks in the city. A septic tank survey and public awareness campaign are recommended.

68. Septage in Sihanoukville, where collected, is treated in the anaerobic lagoons of the WWTP. There is currently no constructed service bay for septage off loading, but instead it is emptied into the side of one of the four lagoons. No septage volume or truckload records are taken.

69. This co-treatment of septic sludge is an established method of primary treatment as the septic tank sludge mixes with the sludge from the reticulated wastewater from the service area. This increases the loading to the pond which is beneficial for anaerobic decomposition. If the WWTP upgrade options of either mixing or provision of trickling filters are taken, co-treatment of septage can continue in the anaerobic ponds.

3.5.2. Cost estimates

70. The cost estimate for this wastewater and sludge co-treatment subproject is $14,653,560.

3.6. Siem Reap Sewer

3.6.1. Failure of Existing Interceptor Sewer

71. The interceptor sewer was installed under the SRWM project between 2007-2009 and commissioned in 2010. It consists of 632m of 600mm GRP pipe and 3,043m of 700mm GRP pipe. It begins at National Road NR6 running north to south down Sivatha St, then turning southwest onto Wat Chork St, crossing the Ring Road, and ending at a pump station. From this pump station wastewater is delivered to the WWTP, also constructed under the SRWM project.

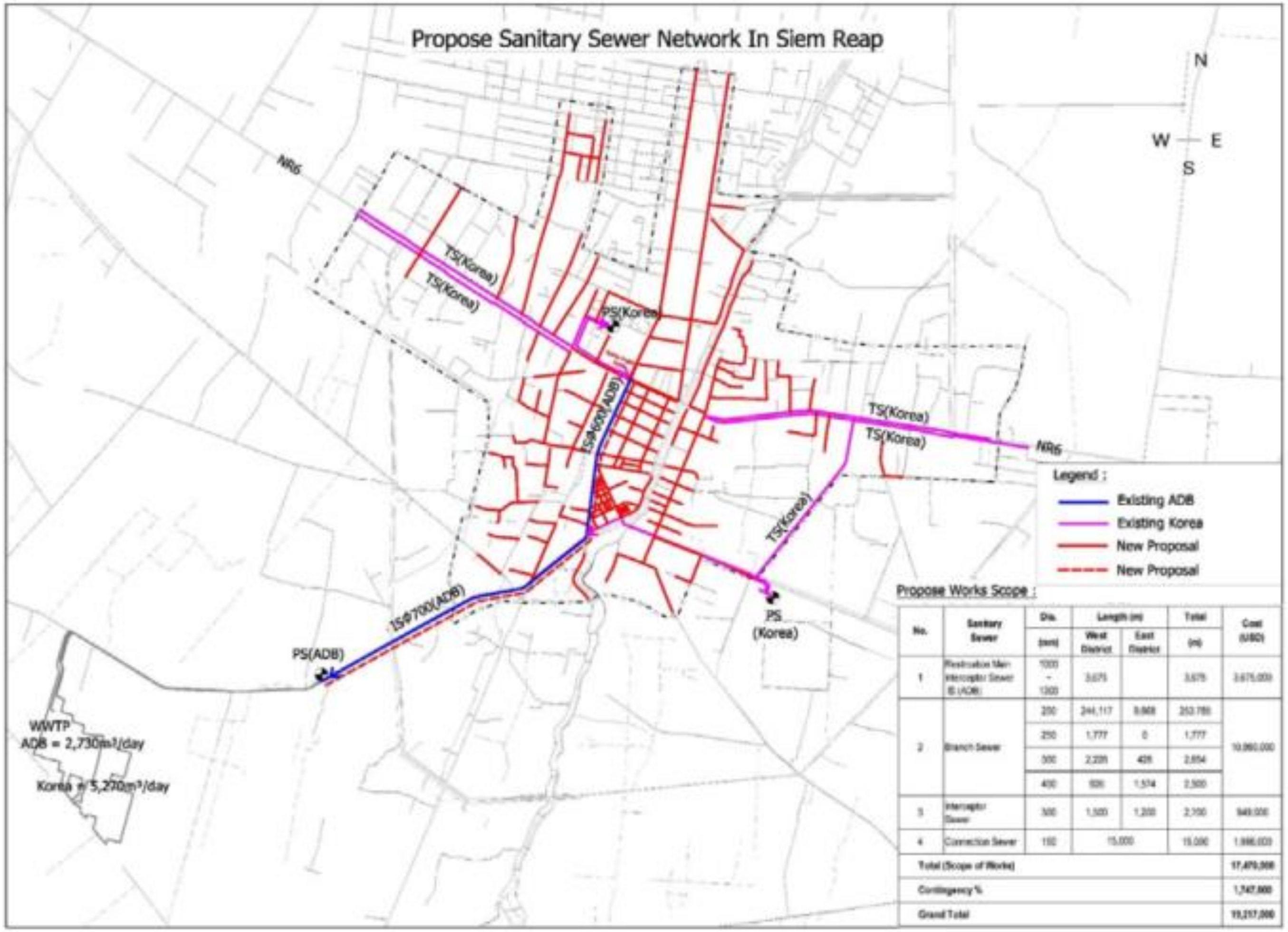
72. The pipe invert at the upstream end was at 3m depth (600mm dia) and at the downstream end reached its maximum IL depth at 8.3m (700mm dia). The grade of the 632m of 600mm pipe was 0.237% and the downstream 3,043m of 700mm pipe 0.187%.

73. Between 2011 and 2014, the road surface above the pipeline failed in 5 locations. In the furthest up stream failure the top of the pipe deformed inwards at the top and developed a leak at the top, but did not break. In the four downstream cases the pipe failure was a typical compression failure with complete collapse at all 4 road failure locations. Three of these collapse locations have been fully repaired, the upstream deformity has had a temporary repair and backfill, and the fifth failure point around 500m upstream of the pump station has not been repaired due to lack of budget. The pipe remains closed at this location. Therefore the interceptor sewer is not functioning.

74. Further failures could happen at any time, and there may be many more deformed areas of pipe that have not been detected yet as there is no road collapse evident. Failure along any part of this pipe means that there is no way for wastewater to reach the WWTP, and all of it is discharged via overflow weirs to the town drainage.

75. The layout is shown in Figure 3-10.

Figure 3-10 Current WW infrastructure in Siem Reap



3.6.2. Options for replacing interceptor sewer

76. There are three main options for replacing the 3.7km length of interceptor sewer. All options will include increasing the capacity from the current 600/700mm diameter and using a stronger pipe material such as ductile cast iron (DCI). The options are :

- Option 1: Same deep alignment as existing, using trenchless technology for one 1000mm diameter DCI pipe
- Option 2: Shallower alignment with multiple (3-4) in-line pump stations, using open cut trenching for one 1000mm diameter DCI pipe.
- Option 3: Same deep alignment as existing, using open cut trenching for one 1000mm diameter DCI pipe.

77. Pipe sizes above are suggested sizes only and will need to be confirmed during detail design.

78. Option 3 has been discounted due to the serious problems experienced on the original project with dewatering, proper compaction, operating in a deep trench, necessary road closures, disruption and mess in the main tourist area and economic losses from affected businesses and associated tax revenue to the government.

79. During the initial 2006 design, a cost comparison was made between deep trenching for a gravity-flow pipe against shallow trenching with multiple pump stations, and the outcome was that the lifetime cost effectiveness was better for trenching without pumping up to a depth of 10m.

80. Currently, if the interceptor was in working condition, the flow would be limited to 25,800m^3/day which is the maximum capacity of the 600mm pipe. This is sufficient for the central and western areas up to and beyond 2030 as a wastewater flow of 16,000m^3/day is projected for these areas by 2030. However, as the pipe needs to be deep due to the flat topography of Siem Reap, is expensive and difficult to construct, it should be sized for a much longer lifetime and a 50 year life to 2070 is suggested.

3.6.3. Time Horizon

81. The wastewater generation estimate for the east and west service areas by 2070 based on a 2015 generation of 14,157m^3/day and a growth rate of 3% is 71,950m^3/day. If the eastern area is disconnected from the trunk sewer and diverted to a new separate WWTP as proposed by the Korean project design, then the required 2070 wastewater capacity of the proposed trunk sewer replacement will reduce to 47,000m^3/day. A 1000mm diameter pipe will be able to take this flow.

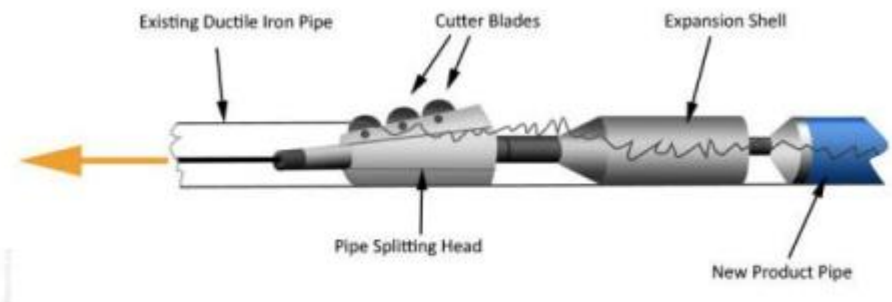
3.6.4. Options for trunk sewer replacement - Trenchless Technology

82. The preferred construction method is pipe bursting with pipe splitting to replace the existing 600/700mm diameter GRP pipe with 1000mm lined DCI pipe. Pipe splitting has an advantage over pipe jacking in that the same existing alignment can be used and the

amount of excavated spoil requiring disposal offsite is less. Otherwise, pipe jacking is also a good option and is of a similar cost.

83. However it is recognised that large diameter pipe bursting is a specialised activity and that the relatively small number of regional companies involved in this method of trenchless technology may cause problems in securing a contractor in the timeframe desired. The Design-Build contract will therefore leave the methodology open to other trenchless technology methods such as pipejacking, both in order to maximise the number of potential interested bidders and take advantage of the expertise of these companies in putting forward alternative solutions.

Figure 3-11 Typical pipe splitting equipment



84. The capital cost estimates, whilst preliminary at this stage, show the trenchless option to be around 18% more expensive than shallower open cut with 3 pump stations. This difference is mainly in hiring the pipe bursting equipment and operator team.

However, the lifetime cost of the trenchless option is significantly less due to having no ongoing power costs.

3.6.5. Cost Estimates

85. Companies were generally not willing to provide quotes or cost estimates outside of a formal bidding process. Costs vary widely based on factors such as geology, access, availability of existing service plans, local auxiliary equipment hire etc. Seven quotes were obtained but the estimates are based on 3 Chinese quotes and one US quote.

86. The cost estimate for this sewer pipe replacement with pipe bursting and installing a 1000mm DCI pipe is $15,911,610

87. Should pipejacking be selected as the preferred methodology, the cost will likely be an increment higher than the cost for pipe bursting to reflect the hire cost of more sophisticated mechanical and electrical equipment.

4. Site Visits and Meetings

4.1. Site Visits

88. Site visits were carried out between May 5th to May 9th 2017. Site photo records are given below.

4.2. Battambang

4.2.1. Water Supply

Figure 4-1 Proposed River Raw Water Abstraction Point

Figure 4-2 Proposed Water Treatment Plant Site


Figure 4-3 Kanghot Irrigation Dam upstream of Off-take Point

4.2.2. Wastewater and Sanitation

Figure 4-4 Battambang Old WWTP

Figure 4-5 Battambang Site New WWTP

4.3. Kampong Cham

4.3.1. Water Supply


Figures 4-6 and 4-7 Existing Raw Water Pump Station and Proposed Raw Water Off-take

Figure 4-7 Existing Off-take Point and Pumping Station

Figure 4-8 Kampong Cham Existing Water Treatment Plant

4.3.2. Septage Treatment


Figure 4-9 Kampong Cham Septage Site

4.4. Sihanoukville

4.4.1. Wastewater and Sanitation


Figure 4-10 Site of a Sihanoukville Pumping Station and Existing WWTP Lagoons

4.5. Siem Reap

4.5.1. Wastewater/ Drainage (trunk replacement)

Figure 4-11 Trunk Sewer Manhole and Pumping Station

Figure 4-12 Siem Reap Waste Water Treatment Plant and Lagoons

4.6. Meetings

89. Consultations took place with senior management of MPWT and the use of FRMI was recommended.

90. The PPTA included consultations with MIH, MPWT and their provincial departments on key matters relating to water safety, as part of the design to institutional support including support to developing water safety plans. During these discussions, issues related to climate change that were discussed included (i) effects of flooding after rainfall events at the WWTPs at Sihanoukville and Battambang, (ii) periods of insufficient water supply during drought periods, particularly at Battambang where the system is reliant on the Sangké river which also supplies irrigation schemes, (iii) effects of periods of high temperature on water consumption, and (iv) risks of drought and higher temperatures causing impaired wastewater plant function and inadequate water to flush the sewerage system. Features of the preliminary design carried out by the CDIA team that address these were discussed. In all cases it was agreed that measures incorporated into preliminary design were appropriate, but that detailed design would need to be informed by more detailed analysis of climate related risks

5. Assessing Climate Change

5.1. ADB's Climate Risk Management Framework

91. The climate risk management approach of the Asian Development Bank (ADB) aims to reduce risks resulting from climate change to investment projects. ADB's framework identifies climate change risks to project performance in the early stages of project development, and incorporates adaptation measures in the design of projects at risk. ADB climate risk management framework comprises the following steps:

i. context-sensitive climate risk screening at the concept development stage to identify projects that may be at medium or high risk;
ii. climate change risk and vulnerability assessment during preparation of projects at risk;
iii. technical and economic evaluation of adaptation options;
iv. identification of adaptation options in project design; and
v. monitoring and reporting of the level of risk and climate-proofing measures.

5.2. Climate Risk Screening

92. All ADB projects are screened for climate risks. An initial screening identifies medium or high risks which need further screening. Risks considered are those resulting from temperature increase, precipitation change, wind speed change, sea level rise, solar radiation change, water availability, flooding, tropical storms, wildfire and landslide.

5.3. Climate Risk and Vulnerability Assessment

93. A detailed climate risk and vulnerability assessment is carried out for projects classified as medium or high risk during project preparation. The assessment aims to quantify risks and identify adaptation options that can be integrated into the project design. The level of technical rigor of the assessment depends on the project complexity and availability of climate data and information for the project area. It can range from a simple desk analysis to a complex assessment based on custom climate projections to enable a more detailed assessment. This was the approach adopted in this study with site specific climate change projections being produced.

5.1. Technical and Economic Evaluation of Adaptation Options

94. Based on the climate risk and vulnerabilities assessed, adaptation options are identified and evaluated on the basis of their technical feasibility and economic viability. Technical feasibility evaluates whether proposed engineering and non engineering measures can be implemented with available skills, equipment, and other local factors such as geography, governance, and capacity.

95. The economic analysis involves estimating and comparing the cost and benefits of the project based on two different scenarios: (i) the project under climate change without adaptation measures, and (ii) the project under climate change with adaptation measures. It aims to identify which adaptation option yields the highest net benefit. It also aims to

estimate the incremental cost of adaptation as the cost of project activities aimed at addressing specific climate vulnerabilities. Recognizing that investing in adaptation measures may be costly and that future benefits may be uncertain, the economic analysis can also point to the best timing for investing in adaptation. It is possible that interventions can be scheduled for a later time without compromising effectiveness of options. These can be classified as "No Regrets Decisions".

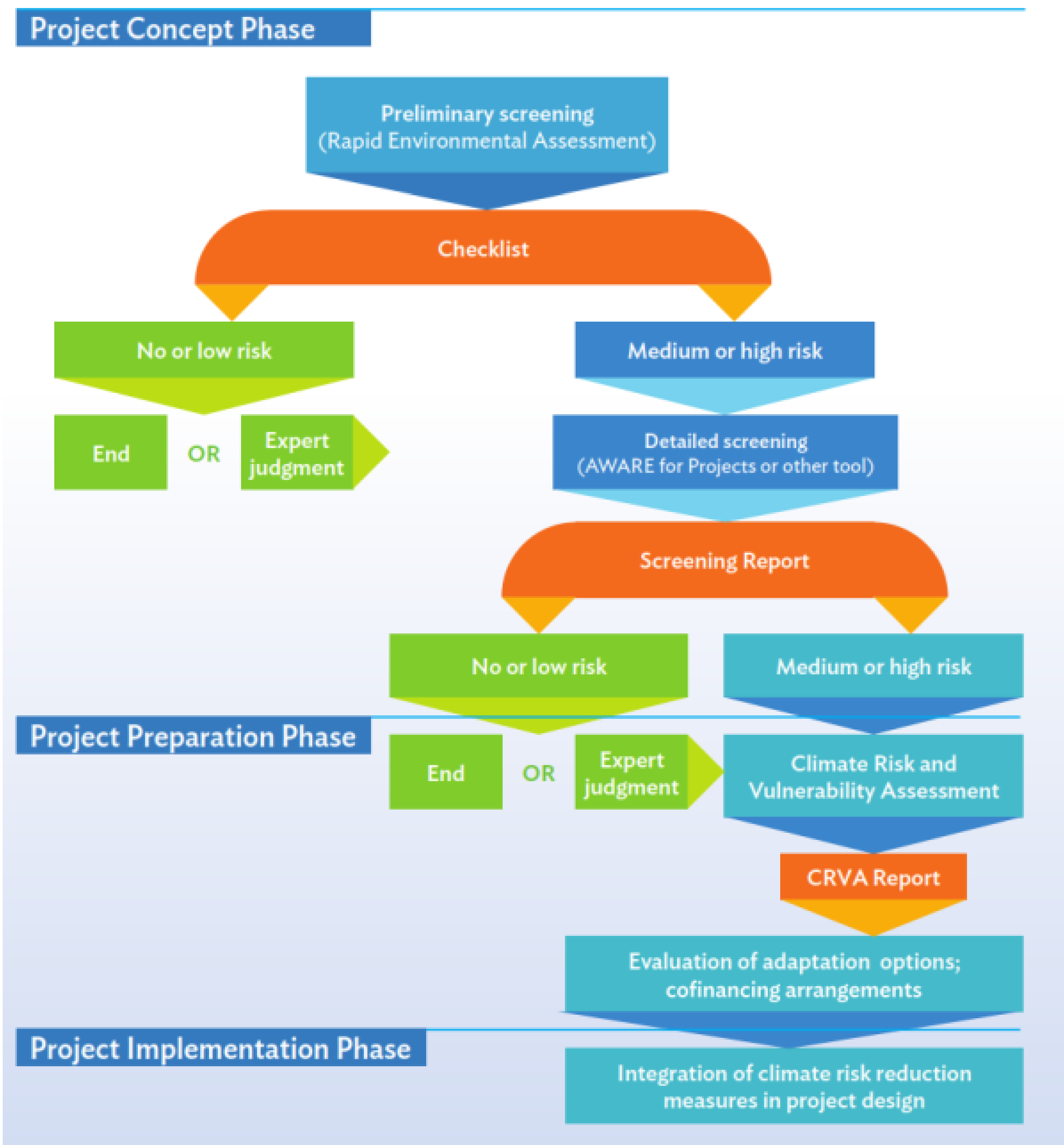


Figure 5-1 Risk Assessment Process

96. Decision makers may elect to invest minimally at the early stages of a project but ensure that the project can be climate proofed in the future if and when circumstances indicate this to be a better option than not climate proofing. This decision ensures that the project is “ready” for climate proofing, if and when required. This is known as "climate readiness" and avoids the foreclosure of climate-proofing options and preserves flexibility to improve climate resilience as climate change is actually observed as opposed to projected.

5.2. Identification of Adaptation Options

97. The most viable adaptation options or climate proofing measures are identified in consultation with the executing agencies or project sponsors, and are integrated in the project design. There is no standardized approach to climate proofing. In some cases, climate proofing is essential to ensure the project is not negatively affected by climate change. In other cases, the lifetime of the project is such that climate proofing is not a viable option or climate readiness is a more appropriate approach. Climate proofing may involve adjusting engineering design such as increasing drainage capacity of water supply systems, elevating roads in areas particularly at risk from flooding, or ecosystem-based adaptation measures such as revegetation of unstable slopes.

5.3. Monitoring and Reporting

98. The level of risk identified during project concept development and the findings of climate risk and vulnerability assessment carried out during project preparation are documented within ADB. The level of risk assigned to the project and the budget allocated to the incremental cost of adaptation are recorded for monitoring and reporting purposes.

5.4. Climate Proofing Projects

99. The process of climate proofing investment projects aims both at assessing the climate risk to a project’s future costs and benefits and at undertaking a technical and economic analysis of options to alleviate or mitigate those risks. Accounting for climate change at the outset of the project cycle does not imply that climate-proofing measures with large and costly investments need to be put in place as project implementation is initiated. It does imply, however, that decisions about project design and the adoption and timing of climate-proofing measures be informed with the possible impacts of climate change in the initial phases of the project cycle and that decisions of an irreversible nature be avoided. This is the essence of "No Regrets" Decisions.

6. Potential Impacts of Climate Change on Water Supply and Sanitation

100. There are many potential impacts of climate change on water supply and sanitation related projects.[7] These are discussed below.

6.1. Changes in Precipitation

101. Changes in precipitation can affect water supply availability and quality in the following manner :

- Reduced precipitation levels can decrease the availability of both surface water and groundwater.
- Increased precipitation intensity and flooding can overwhelm existing drainage infrastructure.
- High-intensity precipitation may increase erosion; larger sediment loads may result in more rapid sedimentation of storage reservoirs, reducing storage capacity.
- Changes in the amount of rainfall may affect the performance and operation of water systems; increases in precipitation may put pressure on urban drainage systems while sewerage systems may become more difficult to operate and maintain if precipitation levels and discharge decline.
- Long-term rainfall increases may elevate groundwater levels, decreasing the efficiency of natural purification processes and increasing the risk of infectious disease and exposure to toxic chemicals.

6.2. Changes in temperatures

102. Changes in ambient air and water temperatures can affect water supply availability and quality in the following manner :

- In some instances, warmer temperatures may improve biochemical treatment processes, particularly in cold regions or seasons; in other instances (particularly in warm areas), the efficiency of these processes may be reduced if critical thresholds are exceeded.
- Temperature increases may result in a reduction of surface water availability by decreasing runoff and increasing evaporation from lakes and reservoirs.
- Higher water temperatures will decrease dissolved oxygen capacity, potentially leading to hypoxia, toxic algae growth, and proliferation of waterborne diseases.
- Higher temperatures may increase agricultural water demand due to decreasing soil moisture and increasing evapotranspiration demand.
- Increases in periods of intense heat may result in higher water demands for domestic and industrial uses.

[7] Guidelines For Climate Proofing Investment in the Water Sector : Water Supply And Sanitation, ADB 2016

6.3. Changes in extreme weather events

103. Changes in frequency, duration, severity, and distribution of extreme weather events can affect water supply and sanitation services and infrastructure in the following manner :

- Service disruptions may increase due to breakdowns in water distribution pipelines from extreme events, such as unseasonal precipitation patterns and flash floods.
- The structural integrity of basic water infrastructure may deteriorate due to floods and periods of intense heat and cold.
- Increases in the intensity of floods may result in the contamination of water sources and may increase the incidence of waterborne and water-related diseases.
- Increases in the frequency and intensity of droughts will cause reduced surface discharge and falling groundwater tables, which can lead to increasing source water pollution and to the drying up of wells, extending the distances that must be travelled to collect water.

6.4. Changes in Sea Conditions

104. Sea-level rise and storm surges put water supply at risk in the following manner :

- Saline intrusion in low-lying coastal areas may contaminate aquifers and force currently secure water sources out of use.
- Saltwater intrusion may corrode materials used in water distribution.
- Coastal storms in combination with sea-level rise can damage coastal water supply and wastewater treatment facilities.
- Ocean discharge from treated wastewater outfalls can be impaired by sea-level rise, particularly during high tides or storm surges.

6.5. Adaptation Measures

105. Various adaptation measures are available such as the following:

- Water supply can be protected against increasing variability of seasonal and annual precipitation and runoff by building additional water storage infrastructure, such as reservoirs or storage tanks, to provide buffers.
- Adjusting infrastructure designs and introducing flexibility in water systems operations can build resilience to changing climatic conditions such as changes in the seasonality of precipitation and changes in flood return periods.
- Diversifying water supply sources—including conjunctive use of surface and groundwater, reuse and recycling, and use of household-level water sources such as roof water harvesting—can mitigate the impacts of weather-related disruptions on any given component of the water supply system.
- Flood protection infrastructure can help prevent contamination of water supply sources and treatment works. In some cases, water storage can also contribute to downstream flood control.
- Increasing coverage of community water supply infrastructure can improve dependability under changing climatic conditions.

- Green roofs, street trees, wetlands, and porous paving can reduce the volume of stormwater runoff and decrease pressure on wastewater treatment facilities.
- The preservation of riparian wetlands upstream of water users can improve water quality and quantity and provide flood protection at times of high-intensity or long-duration precipitation.
- Separation of stormwater and sanitary sewers can minimize the risk of overwhelming collection systems and water treatment facilities in times of heavy precipitation.
- Integrated water resources management within river basins can improve the allocation and management of scarce water resources in the context of climate change.
- Promoting the efficient use of water through programs, incentives, and technologies for water conservation and water recycling can help reduce water demand.
- In coastal areas, water utilities can utilize desalination of seawater or brackish water to supplement insufficient freshwater resources.
- A properly prepared disaster response strategy can reduce the negative effects of water service disruptions, particularly to critical services such as sanitation and domestic water supply.
- Ensuring that water authorities and stakeholders are equipped with adequate data, information, and skills will help them to respond to the impacts of climate change.

6.6. AWARE for Projects

106. AWARE for Projects is an online tool used by ADB project teams to screen projects for climate risks. The tool uses data from 16 general circulation models, as well as databases on temperature increase, wildfire, permafrost, sea ice, water availability, precipitation change, flooding, snow loading, tropical storms, and landslides. For each project screened, the tool generates an overall climate risk ranking of low, medium, or high; key risk areas; and narratives on potential impacts and adaptive measures to guide subsequent activities. The following diagrams quote the findings for climate risk and for and geological hazard risk for the wastewater and for the water supply subprojects.

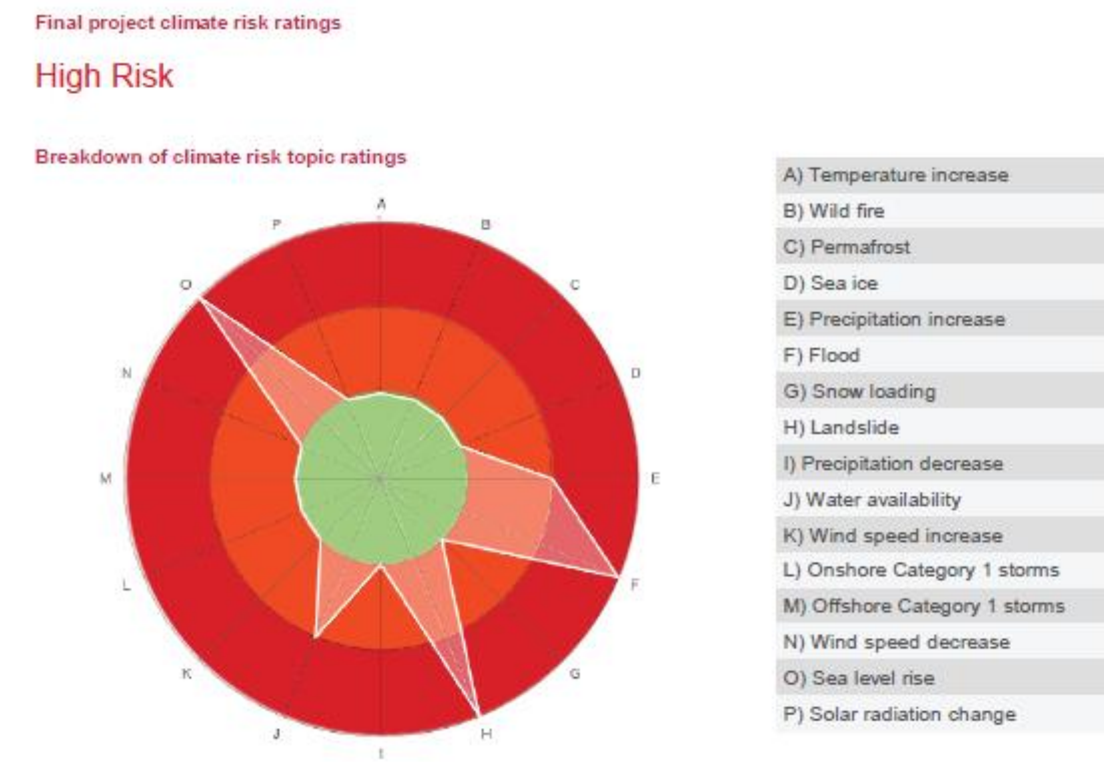


Figure 6-1 AWARE climate risk ratings for wastewater subprojects

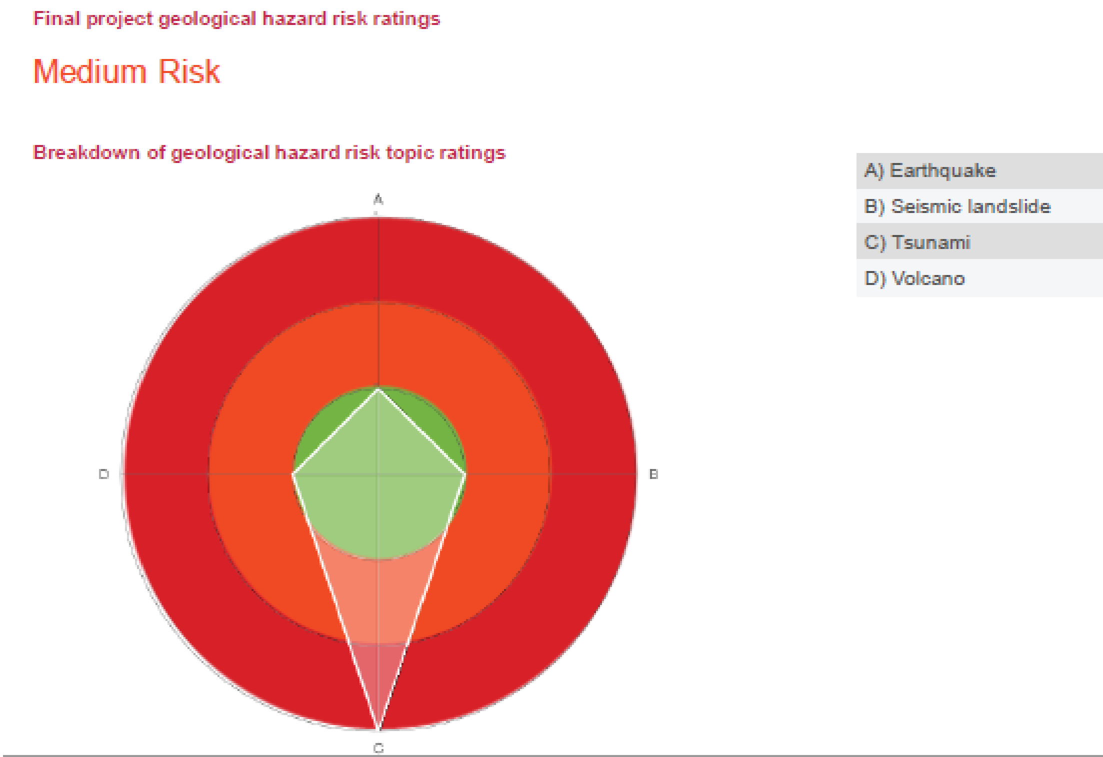


Figure 6-2: AWARE geotechnical hazard risk ratings for wastewater subprojects

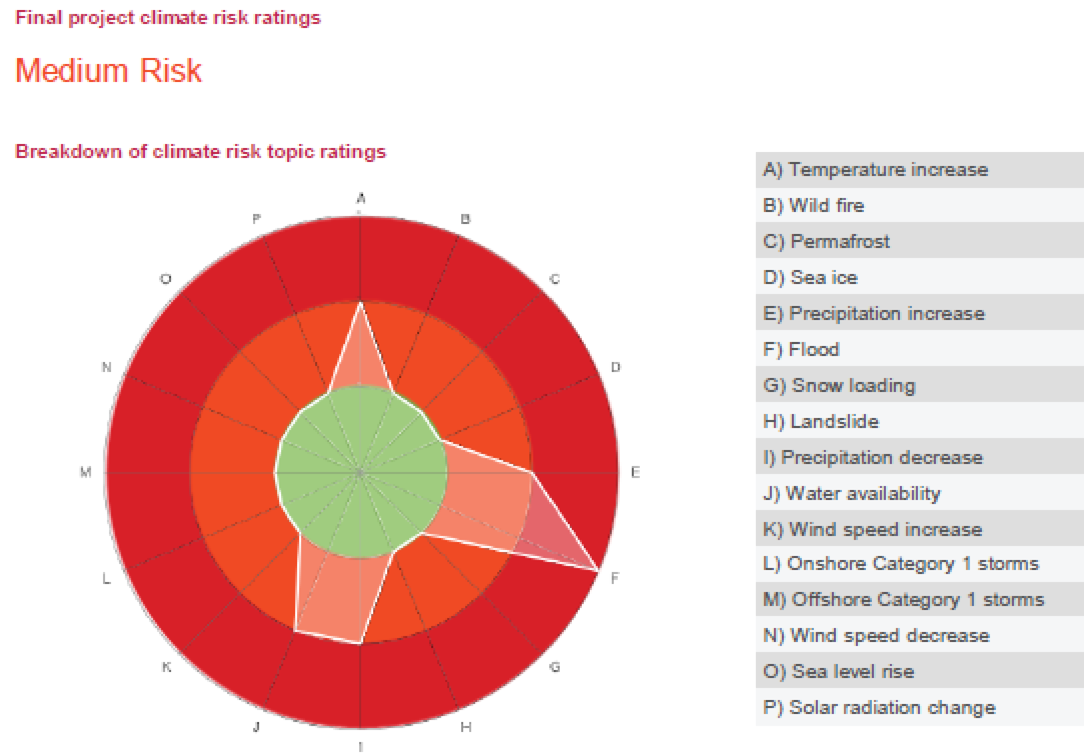


Figure 6-3: AWARE climate risk ratings for water supply subprojects

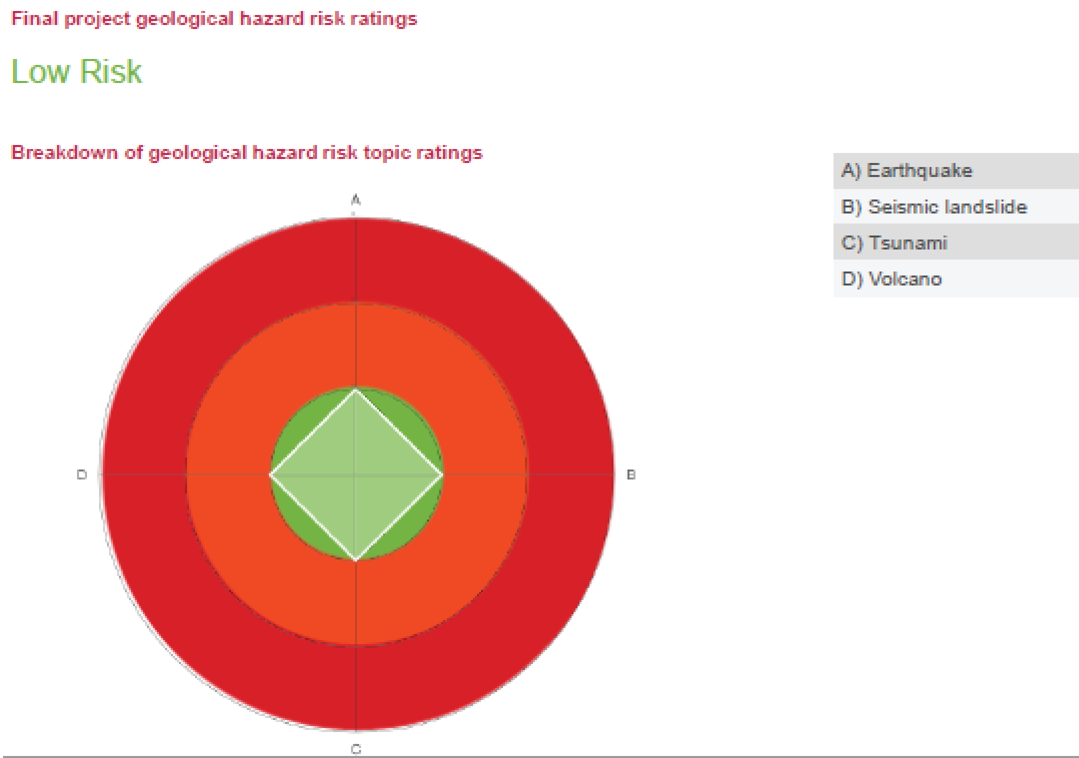


Figure 6-4: AWARE geotechnical hazard risk ratings for water supply subprojects

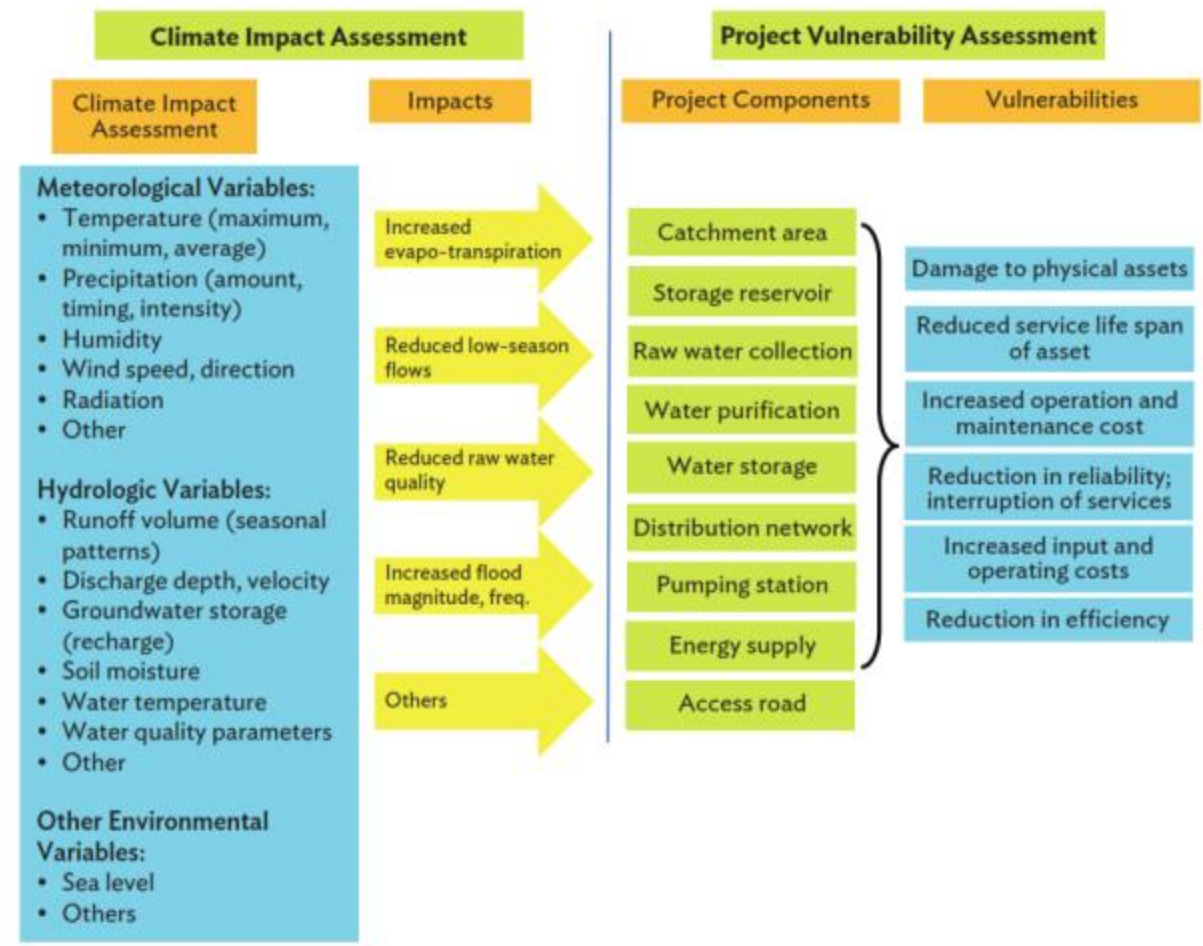
107. The AWARE tool identifies potential climate hazards as (i) flooding, (ii) landslides and (iii) sea level rise and tsunamis as a potential geotechnical hazard. The tool is intended as a "first step" to flag potential issues that are subsequently checked in relation to project context and components. Site visits and analysis of data would concur with risks of flooding and, in the case of Sihanoukville, tsunamis. However landslide risk, or slope stability in general, are very unlikely to affect the proposed improvements in any of the towns.

7. Assessing Vulnerabilities

7.1. ADB Guidelines

108. The vulnerability assessment examines each project component or asset and attempts to establish causal relationships. This is shown in Table 7-1. [8]

Table 7-1 Conceptual Framework for Climate Risk and Vulnerability Assessment



109. Vulnerability refers to the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change. Vulnerability, exposure and adaptive capacity are very dependent on local conditions and often highly site-specific.

There are four sites under consideration :

[8] Guidelines For Climate Proofing Investment In The Water Sector Water Supply And Sanitation, ADB 2016

- Kampong Cham
- Siem Reap
- Battambang
- Sihanoukville

110. Each has been assessed individually based on local knowledge and local conditions.

7.2. Adaptation Assessment

111. The goal of the 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 damage caused by the changing climate and to take advantage of the opportunities that a changing climate may present.

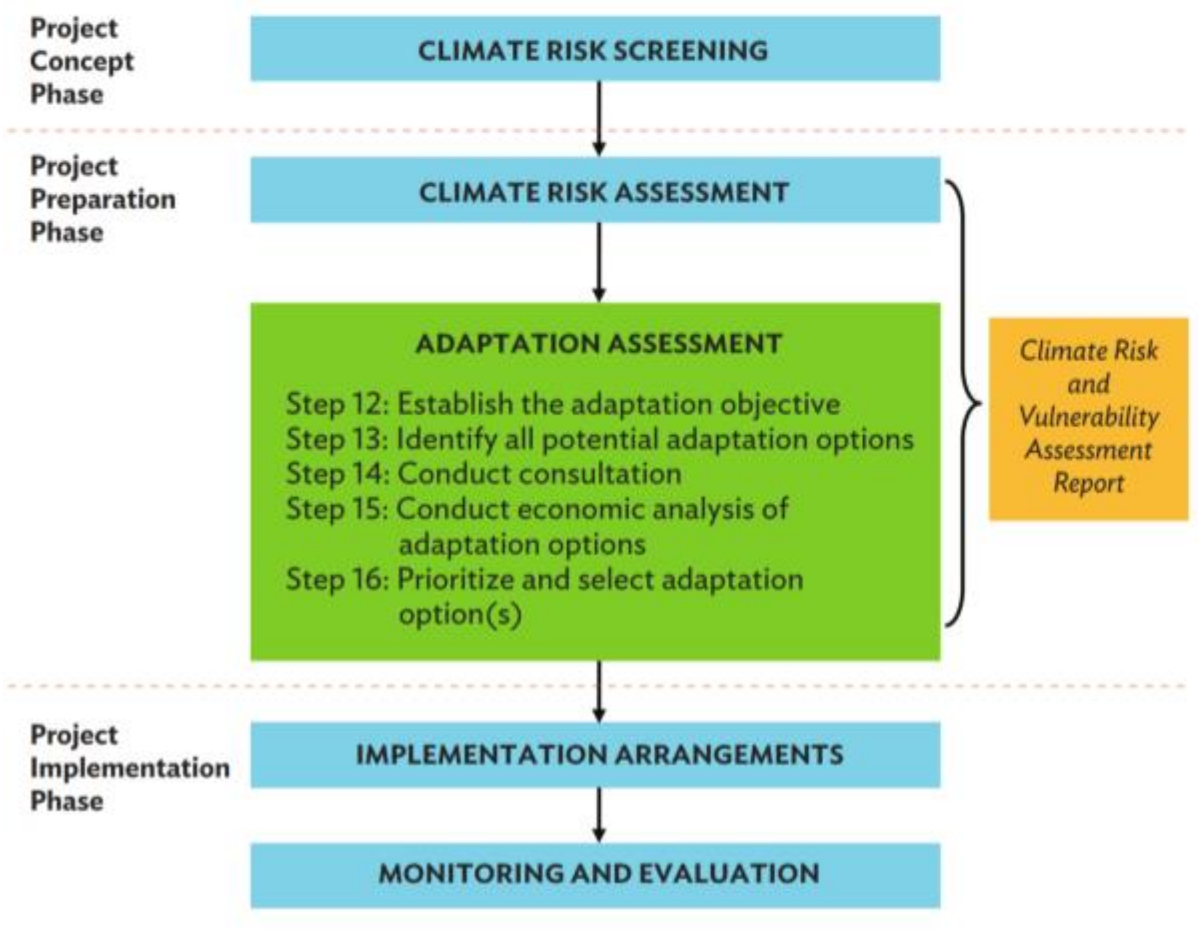


Figure 7-1 Climate Change Adaptation Assessment

112. It may be necessary to carry out an economic assessment. A key feature of the economic analysis approach is that it recognizes that the costs and benefits of the climate-

proofing options must be assessed by identifying and quantifying the climate change impacts along two scenarios:

- Scenario without climate proofing: What are the expected impacts of climate change on the project in the future if there were to be no climate-proofing measures in place?
- Scenario with climate proofing: What are the expected impacts of climate change on the project in the future if there were to be climate proofing measures in place?

7.3. Climate Change and Water Governance in Cambodia,

113. Cambodia has abundant water resources but they are spatially and temporally unevenly distributed. In reality, many communities face problems brought on by too much or too little water. This situation is compounded by the effects of catchment degradation caused by physical alteration of inland water systems (both quantity and quality), deforestation and habitat destruction, water withdrawal for agriculture, mining and urbanisation, pollution, and hydrological and environmental changes due to infrastructure developments within and outside of Cambodia[9]

114. It is acknowledged that uncertainties stem from incomplete knowledge of the climate system and its representation in climate models. Downscaled data using regional climate model and global climate model datasets is coarse and based on uncertainty in the trajectory of future emissions and concentrations of greenhouse gases and aerosols. Natural variability inherent in the climate system is another cause of uncertainty.[10]

7.4. Climate Change Strategic Plan for Water Resources and Meteorology 2013-2017

115. The Kingdom of Cambodia is considered one of the most water-abundant countries in the region. There are two types of fresh water available in Cambodia: annually around 75,000 million cubic meters of surface water runoff; and 17.6 million cubic meters of aquifer ground water.

116. Rivers and streams, lakes, aquifers and marine water are important sources for national economic development in many sectors, such as agriculture, manufacturing and small-scale industries, hydropower, navigation, tourism, environmental protection and daily life. Cambodia's economy is highly dependent on water.

117. The importance of water for food production, rural livelihoods and economic development is recognized in the Government's Rectangular Strategy (RS) on Growth, Employment, Equity and Efficiency, the National Strategic Development Plan (NSDP) and the Strategy for Agriculture and Water Resources.

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[9] Climate Change and Water Governance in Cambodia, Challenge and Perspectives for Water Security and Climate Change in Selected Catchments, Cambodia, Cambodia Development Resource Institute, Phnom Penh, December 2015

[10] Ministry of Water Resources and Meteorology, 2012

118. It has been accepted that Climate Change (CC) will increase water management challenges; less rainfall is anticipated during the dry season and more during the wet season, with more extreme weather events and potentially worse seasonal water shortages and floods.

119. The Ministry of Water Resources and Meteorology (MoWRAM) has committed itself to overcoming the impacts of climate change, introducing a law on water resource management, a national water resource management policy and strategy, and many more guidelines and regulations for better climate change-adapted management and development.

120. Water quality is determined by natural processes, particularly by the dilution effects of water runoff from heavy rainfall, which normally occurs during the wet season. At this time, bacteriological and chemical water quality is generally high, although physical water quality may be reduced because of heavy sediment loads. However, when river flows decline, water quality may deteriorate significantly due to contaminants being diluted to a much smaller extent. In addition, due to human population growth and socio-economic development, water quality has been increasingly threatened, especially during the dry season, and particularly during years of less rainfall.

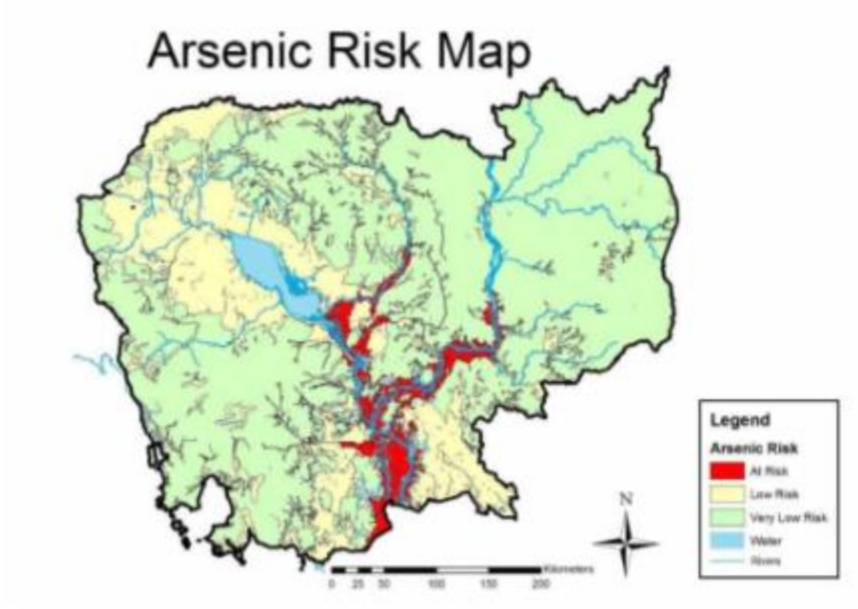
121. Cambodia's climate is dominated by the monsoon, which drives the tropical wet and dry climates. The monsoon brings rain to Cambodia during May to September or early October – called wet season; while the northeast monsoon blows during November to March, bringing dry, cool air, with hotter localized air during late March to late April.

122. Temperatures are fairly uniform throughout the Mekong River Basin, with only small variations from the average annual mean temperature of around 28^{o}C and the average maximum and minimum temperatures of 34^{o}C and 21^{o}C, respectively. The coldest temperature can be as low as 10^{o}C during the month of January. The warmest month is in April, during which the temperature can be as high as 38^{o}C before the rainy season arrives. Normally, typhoons and tropical storms hit Vietnam first leaving Cambodian areas less damaged.

123. The average precipitation rate in Cambodia is 1,600 mm per year. Around Tonle Sap Basin and the lowlands near the Mekong River rainfall varies from 1,300 to 1,900 mm per year.

124. Most Cambodian people face a shortage of fresh water during the dry season, and also during the "small dry season" in the wet season; but in the rainy season they face too much water, and flooding. Irrigation infrastructure is insufficient, old and run-down, which has a severe impact on water storage, distribution and supply, sanitation and food production. The waters of the Gulf of Thailand are enclosed by land, and there is a growing risk that contaminants and sediment from coastal towns, agricultural areas and forest logging may pollute the sea. Furthermore, shipping and off-shore exploration for oil and gas reserves present additional risks to water resources.

125. The most concerning issue for ground water quality is arsenic content. There are many wells exceeding World Health Organization (WHO) guidelines on arsenic content; this is known to be caused naturally, not by human-induced activities. Increased arsenic content in ground water also affects surface water quality.



Source:http://arseniccentercambodia.com/index.php/km/2013-09-26-02-52-06/arsenic-map.html

Figure 7-2 Arsenic Risk Contamination in Cambodia

126. The impact of drought has been addressed by a number of programs aiming to improve the irrigation system, rehabilitation of pumping stations and water pumps, water supply and sanitation, and the establishment of Farmer Water User Committees (FWUC).

127. Extreme weather events, such as storms or typhoons, are not usually considered a major problem in Cambodia as the country is protected by surrounding mountain ranges. Storms do occasionally affect the country, with most storm-related damage being caused by localized floods associated with heavy rain. Tropical storms can also affect the level of Mekong River flooding experienced in a given year. Greatest damage occurs when these arrive during September and October when the seasonal discharge of the Mekong River is already high, and a second significant peak to the annual flood is generated.

128. Wind damages human property such as houses, as well as agriculture and ecological systems. Typhoon Ketsana damaged hundreds of houses in Kampong Thom and Siem Reap in 2009.

129. The vision of the Climate Change Strategic Plan (CCSP) for Water Resources and Meteorology is sustainable use of water resources in adapting to climate change; and timely, trusted weather and climatic information.

130. Cambodia is expected to experience higher and more intense rainfall followed by periods of drought. The effects are likely to include more severe water scarcity and more frequent floods, resulting in crop failures and food shortages. Accelerated loss of biodiversity will negatively affect ecosystems. Coastal communities and eco-systems are likely to be affected by rises in sea levels, and higher temperatures and humidity will create conditions for increased incidence of malaria and dengue fever. The poor and marginalized, particularly women and children, will be worst affected.

7.4.1. Water Availability

131. The impacts of climate change on the water resources sector include problems of increased flood and drought, changes in water supply and water quality, and increased competition for water. The irregular seasonal times of wet and dry months caused by climate change, especially during the last few decades, impacts on water resources management and development efforts. At the same time, there is increased demand for water from emerging sectors, including industry, livestock, domestic use, and especially agriculture; coupled with seasons changing due to climate change, this creates many more social problems. With global warming, Cambodia's temperature has increased making it difficult to prevent loss of water from evaporation. Ground water requires recharging annually from rain water. Due to climate change impacts on the amount of rain water needed to recharge ground water, the recharge rate is seriously reduced, leading to Cambodian farmers having insufficient ground water for farming.

7.4.2. Reservoirs

132. Many reservoirs are gradually getting shallower because of sedimentation, which leads to reduced capacity for water storage. Irrigation systems and hydraulic infrastructure have not yet been modernized, or taken climate change into consideration in almost all areas of the country. Floods and droughts impact on irrigation systems and hydraulic infrastructure. Most importantly, floods cause tremendous negative impacts on irrigation systems located in low land areas.

7.4.3. Dams

133. Frequent floods destroy dams; most of them are old and the impacts of climate change on them have not been considered. Flood Protection Dikes have been destroyed by floods, as during each flood, water overflows on these Flood Protection Dikes. The potential impacts of climate change were not taken into account during their construction and they are made from soil.

7.4.4. Erosion

134. River banks and coastal areas suffer erosion of beaches/banks caused by floods and/or high speed waves, brought on by the impacts of unpredictable climate change, which leads to negative impacts on rural livelihoods, especially on farmers who are completely dependent on limited land areas.

8. Climate Change Projections

8.1. Developing Appropriate Climate Change Scenarios

135. Climate projections are representations of the responses of the climate system to greenhouse gas (GHG) emissions or atmospheric GHG concentrations. They are typically based on general circulation model[11] (GCM) simulations. Climate change projections can be useful in determining how climate variables, such as temperature and precipitation, may change in the future under various assumptions about GHG emissions.

136. However, projections based on climate model outputs are limited by the imperfect representation of the climate system within such models and by uncertainties associated with future GHG emissions among other factors. Therefore, climate projections should not be viewed as forecasts or predictions, but rather as plausible alternative characterizations of future climate conditions. They are helpful in exploring "what-if" questions; they do not aim to provide accurate or definitive predictions of how climate will behave in the future.

There are four generally used climate change scenarios. These are discussed below.

8.2. Climate Change Science

8.2.1. IPCC

137. The Intergovernmental Panel on Climate Change (IPCC) is a U.N. scientific body who produce a series of international assessment reports on the current state of climate change knowledge.(AR5 is the current edition) The release of CO_2 and other greenhouse gasses (GHGs) into the atmosphere will lead to further increases in the average temperature in the future. It is likely that these higher temperatures across the globe will change rainfall patterns. The IPCC has facilitated comparison of GCM (Global Climate Models) by suggesting future $CO_2$and other GHGs related forcing scenarios and standard input data such as temperature, rainfall, wind speed etc. GCMs are constantly being updated and results from each new model are compared to the outputs from all of the others. Then on behalf of the IPCC the World Climate Research Program conducts inter-comparison studies of GCM results.

8.2.2. Future Scenarios

138. Future climate is contingent on human actions (primarily CO_2 emissions) which will depend on societal decisions yet to be taken, so accurately forecasting is impossible in principle. Also caution must be used in attempting to forecast future climates because of uncertainties in the interactions between the oceans, atmosphere and biosphere. As a result GCMs produce a range of modeled future climate situations. These are not attempts to

[11] Computer simulations of air mass and ocean current movements for climate change forecasts and weather forecasts

predict the likelihood of what may happen but the consequences of certain concentrations of GHGs. These are called climate projections.

139. Previous IPCC reports (2000 to 2007) have used the Special Report on Emissions Scenarios (SRES) that make different assumptions about global changes in future greenhouse gas pollution, land-use and other driving forces. Some scenarios have assumed very high rapid economic growth and associated high CO_2 future emissions. Others assume a reduction in the use of fossil fuels with proportionally reduced CO_2 levels.

140. The latest IPCC report (Number 5) uses a new description “Representative Concentrations Pathway (RCP)”. These RCP scenarios are projections of the change in the balance between incoming and outgoing radiation to the atmosphere. The numbers refer to global energy imbalances, measured in watts per square meter, by the year 2100.

141. RCP 2.6 (PD) refers to a scenario where CO_2 emissions peak in the near future and then decline. This is optimistic. RCP 4.5 and 6.0 are intermediate scenarios. RCP 8.5 refers to the most severe case of the 4 scenarios considered. where emissions continue to rise until 2100 leading to global temperature increases. This is pessimistic.

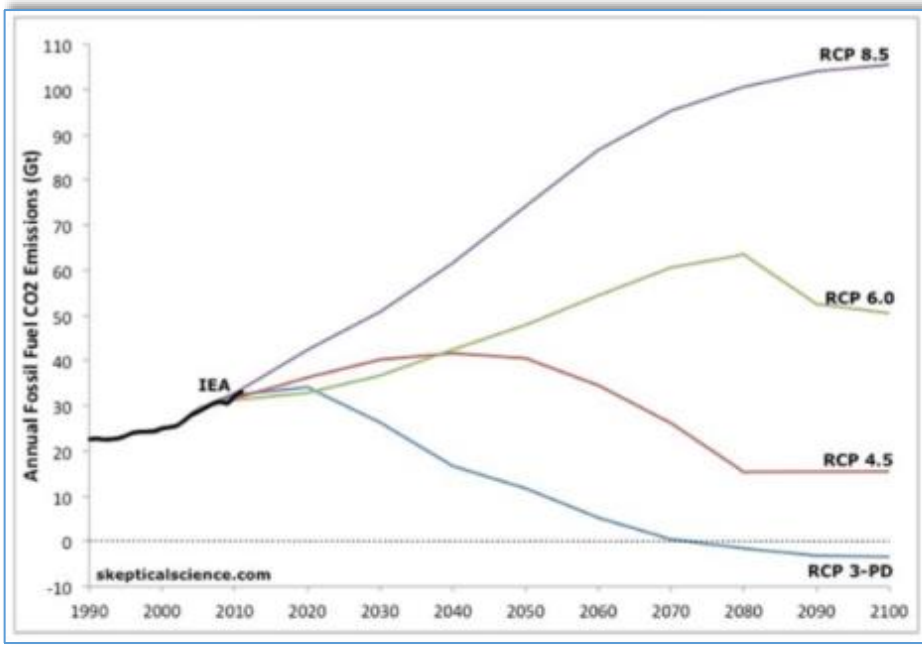


Figure 8-1 RPCs from IPCC AR5 (2011)

142. Recent climate change studies use RCPs of 8.5 for extreme CO_2 future concentrations and values of 2.6 or 4.5 to represent low CO_2 future concentrations. In the projections for MPWT the RCP 8.5 is used. This is a pessimistic scenario which although it is no less likely than the other scenarios and not necessarily the worst case it is designated the “extreme scenario”.

8.3. MPWT FRMI - Flood Risk Management Interface Software

143. Cambodia is one of the pilot countries participating in the Pilot Program for Climate Resilience (PPCR). The PPCR provides incentives for scaled-up action and transformational change in integrating consideration of climate risks and resilience in national development planning, consistent with poverty reduction and sustainable development goals.

144. The improvement of access to knowledge, to its dissemination and its conservation was addressed by the development within MPWT of a knowledge management tool called Flood risk management interface (FRMI). This software provides easy access to information about floods and roads, as well as flood risk maps developed under the CR-PRIP.

145. A copy of the Flood Risk Management Interface (FRMI) Version 1.2 was obtained from MPWT September 2016. In the interviews with MPWT it was recommended that it be used in the Climate Risk and Vulnerability Analysis study (CRVA). FRMI simulates flood risk projections for Cambodia under RCP8.5 for 2050. Further details of outputs obtained from FRMI are given in Section 9.

8.4. CLIMSYSTEMS

146. CLIMsystems of New Zealand were retained to produce projected values for precipitation and temperature under various RCP scenarios for target years of interest at the four sites. Projections were based on historical data for rainfall obtained from MOWRAM. Daily rainfall figures for the preceding 25 years were obtained and utilised. Further details of outputs obtained from the projections are given in Chapter 10.

8.5. Reference Materials

147. As mentioned previously, ADB have published many useful guidelines on climate change and these have been used in the preparation of this report. Two specific ones are highly relevant:

- Sector Briefing on Climate Change Impacts and Adaptation: Water Supply And Sanitation ADB, January 2012.
- Guidelines For Climate Proofing Investment in the Water Sector : Water Supply And Sanitation, ADB 2016

148. In addition we have taken account of the following reports and publications :

1. Mekong River Commission, Roads and Floods, MRC Technical Paper No. 35, 2011
2. Climate Change Impact and Hydrology, MRD June 2013
3. Climate Change Adaptation Options, MRD May 2014
4. Climate Change Adaptation Report August, MRD, (Manley, R) August 2014
5. Reinforcing Community Flood Resilience, MPWT, August 2014
6. Report on Knowledge Management, MPWT, June 2015

7. Non Mandatory Guidelines for Flood Proofing Roads, MPWT September 2015
8. Road Design Standard Changes Report, MPWT September 2015
9. Flood Risk Management Interface Manual, MPWT, September 2015
10. Vulnerability Mapping Report, MPWT, January 2016
11. Climate Modelling Report, MPWT, January 2016

9. MPWT FRMI

9.1. Flood Risk Management Interface - FRMI

9.2. FRMI Methodology

149. The FRMI methodology consists of identifying of road links and parameters based on topographical analysis of road physical parameters and assessing the flooding types that they are exposed to. The topographical analysis is derived from Shuttle Radar Topographic Mission (SRTM) data available from public internet sources. Topographical data is based on remote sensing not physical site measurements.

150. Road segments from the National and provincial road network are sourced from MPWT RAMS data and catchment areas. Other geographical parameters are then calculated for each road segment. Road resilience is derived from its condition level as provided by the RAMS system. Finally, flood impact or damage risk assessments are carried out for four specific types of flood and mapped.

9.3. SRTM Accuracy

151. The approximate accuracy of a road location and elevation can be obtained from SRTM but that accuracy is in principle limited by the size of the grid utilized. The SRTM data used in the project was retrieved from a 90 m grid or cell. For such a grid the absolute accuracy of SRTM data ranges from 10 to 20 meters in all directions.

152. The distance of 90 m means that break points, steep slopes or vertical drops would not be traced accurately for countries with significant mountainous terrain, as all slopes are interpolated from point measurements. In low variability terrains like flood plains in Cambodia the overall error in elevation is relatively low. Errors factors of 1 to 2 meters have been established by comparing SRTM data with measured and benchmarked elevations from roads.

9.4. Road Catchment Area vs. River Catchment Area Method

153. The FRMI uses a road catchment area method rather than a river catchment area method, mainly for effectiveness purpose related to data management and better correlation to road impacts. It is possible to calculate every major river catchment area in the whole country and to organize the gained information according to the river flow network. However MPWT data is orientated towards the road network, not the river network. It is much easier to use the existing road section data base as the main analytical unit and attach flooding values to the individual road sections. Also repair budgets are attached to established road sections, rather than catchment areas or river sections.

9.5. Flood Risk Damage Maps

154. Flood risk damage maps have been produced for various types of floods. The road vulnerability maps present four road risk flooding damage indexes corresponding to different flood types. Another index combines the risk of the four flood type for prioritization purposes.

It must be noted that experiencing flooding or being subject to flood risk does not necessarily inflict a lot of damage to every road.

The overall equation is:

Flood damage risk = Risk of flood occurrence x Road condition factors

155. The flood risk calculation process starts by evaluating the risk of occurrence of the four types of flood. The main input is the 1 day or 5 day extreme rainfall event, the drainage areas, slope and shape. This leads to the build up intensity next to the road. It then introduces factors to account for the resilience of the road to these floods. Road resilience is assessed in the model through three indicators, the pavement surface roughness, the pavement type and the condition of the drainage structures.

156. The road resilience factors are then applied in terms of the pavement structure and how efficient the drainage system is under extreme rainfall. Four flood indexes are produced which are then combined into one composite index.

The flood risk indexes are:

- Flash Flood Index
- Large Drainage Area Index
- Build-up Area Flooding Index
- Low Land Flooding Index
- Combined flood risk index

157. The flow chart for this is shown below.

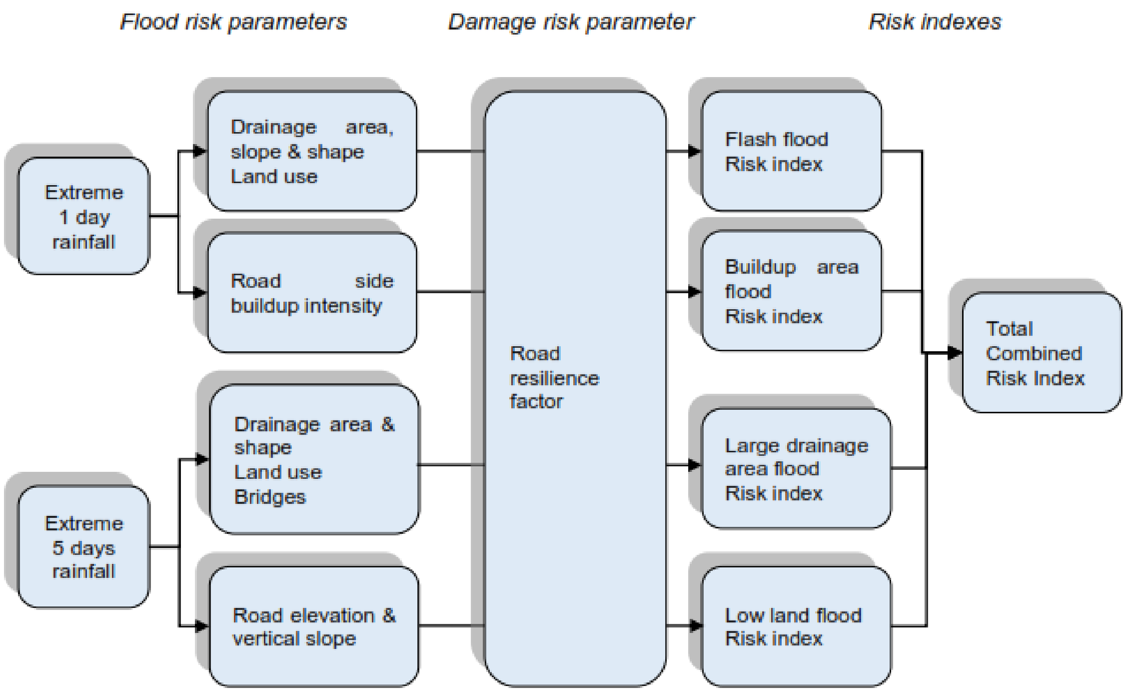


Figure 9-1 Flow Chart for Derivation of Flood Index

158. All these indexes are the basic tools for prioritizing the climate proofing of individual road sections. To this is then added the impact of climate change on the flood risk situation. This is projected to the year 2055.

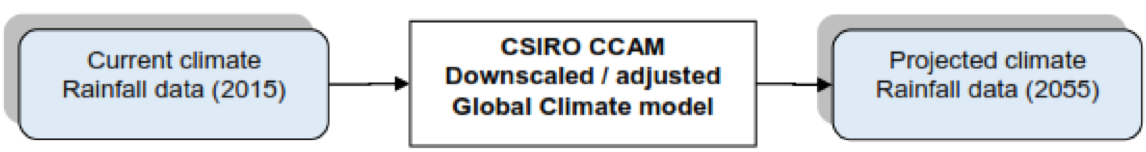


Figure 9-2 Climate Change Analysis

159. A climate change scenario calculation using the projected 2055 rainfall data was carried out and the changes compared to the existing situation. The relevant maps have been produced at the national scale and for all the provinces. The types of maps available are :

- Flood damage risks – current conditions
- Flood damage risks – future conditions
- Flood damage risk changes in time

160. A flood damage risk map shows the road sections associated with four risk levels, ranging from high (red), moderate (orange), low (yellow) to none (green). Maps of the flash

flood analysis show that flash flood risks are located in all provinces where there is mountainous terrain. Highest risk areas are in Mondulkiri, Ratanakkiri and Pursat.

161. Large catchment areas high floods risks are distributed all over the country with no specific patterns as urban flood risk areas and lowland flood risk areas are concentrated along the Tonle Sap and the lower Mekong region. This is where most of the population is located and it is an area of low geographical elevations.

9.6. Multiple Flood Vulnerability

162. For each province each road may be at risk from multiple sources of flooding. The analysis was carried out on the basis of road sections so the entire length of any section may not be susceptible to each flood risk factor and the lengths shown can be an over estimation.

9.7. Climate Change Projections

163. The projections are based on current conditions and future values for 2055 under a high CO_2 climate change scenario which is RCP 8.5.

9.8. Appropriateness of FRMI

164. It is acknowledged that FRMI is targeted at road segments. However it does cover the whole of Cambodia and the flood risks considered are generated by overland flow due to flat terrain or flash floods in water courses. Therefore although roads are the main consideration any other structures in the vicinity may be exposed to a similar level of risk.

165. This software is promoted by MPWT and the consultants were advised by MPWT management to utilise it.

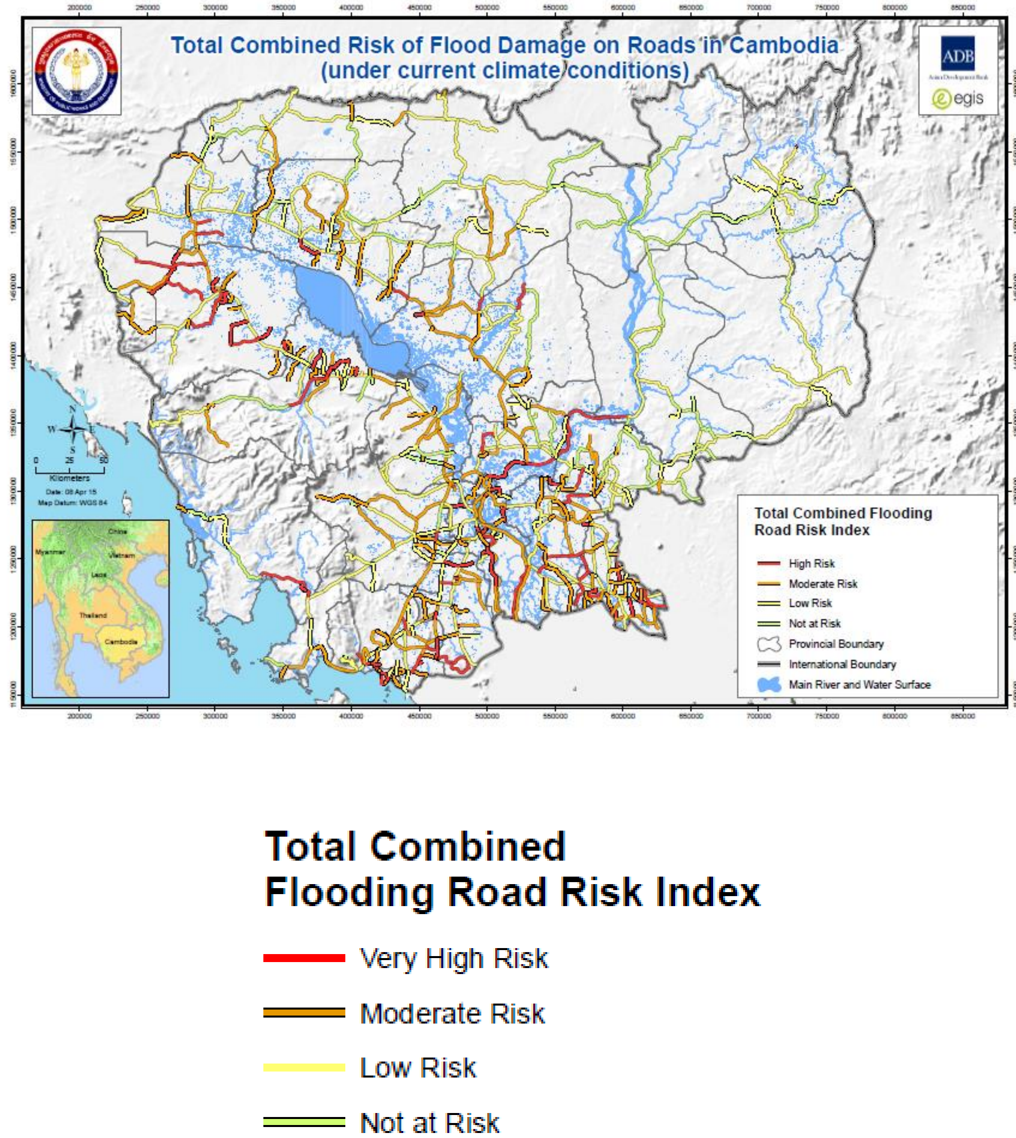


Figure 9-3 National Flood Risk under Current Climate Conditions

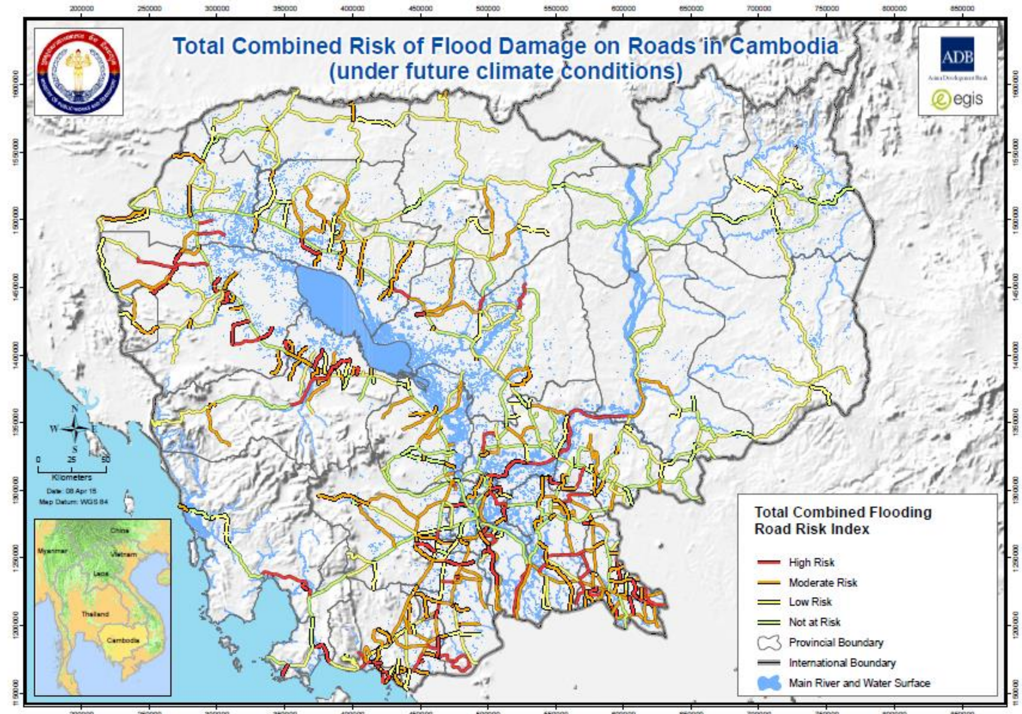


Figure 9-4 National Flood Risk under Future Climate Conditions

9.9. Battambang

166. Under future climate conditions year 2055 RCP 8.5 the area around Battambang is classed as being at Moderate Risk. This location is in the catchment area of the Sangké River which runs off from Mount Aoral.

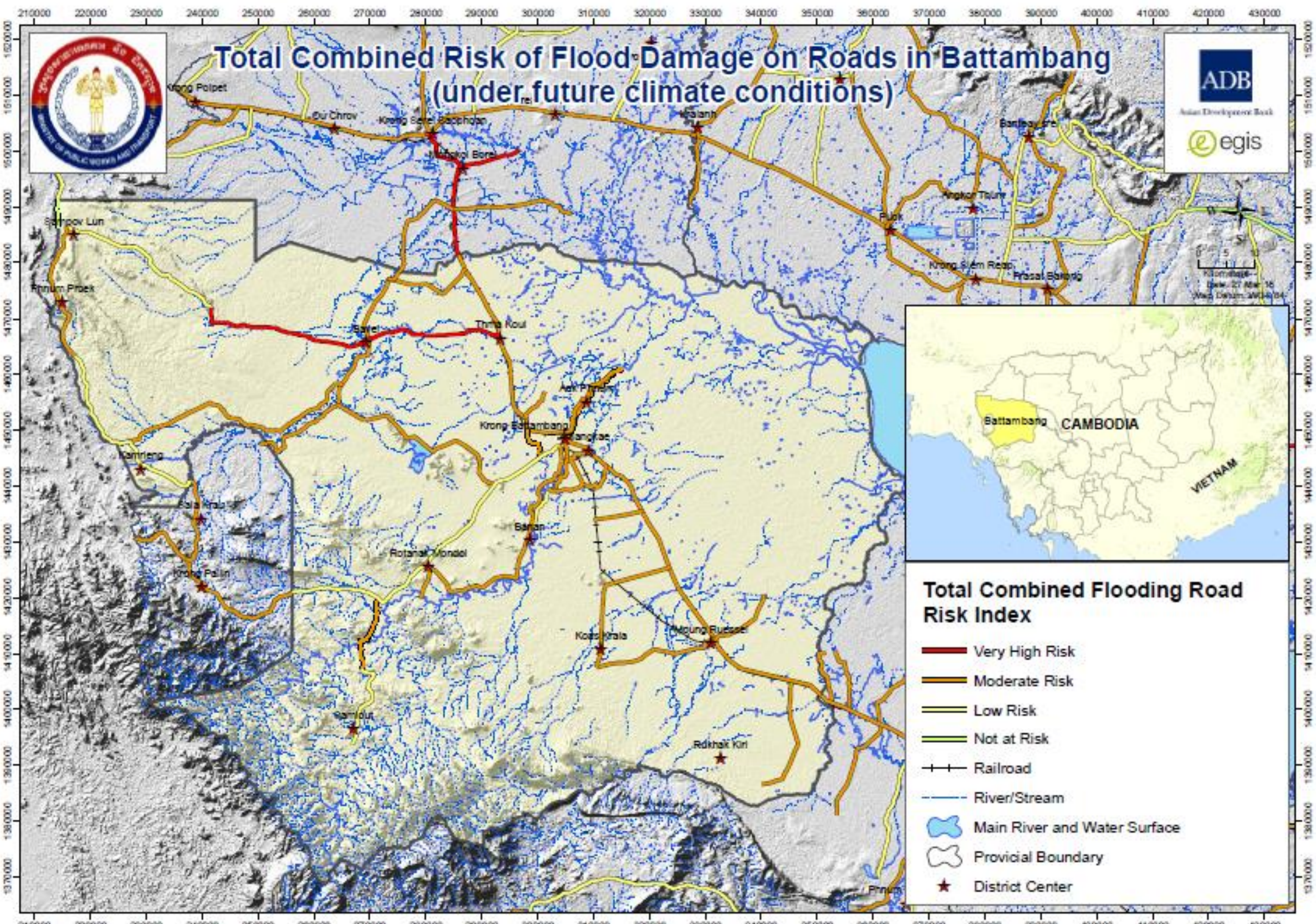


Figure 9-5 Total Combined Risk of Flooding Battambang RCP 8.5 year 2055

9.10. Kampong Cham

167. Under future climate conditions year 2055 RCP 8.5 the area around Kampong Cham to the south, southwest and east is classed as being at Moderate Risk. The area around Kampong Cham to the north and northwest is classed as being at Low Risk. This location is highly influenced by direct flows and overland flows from the Mekong river.

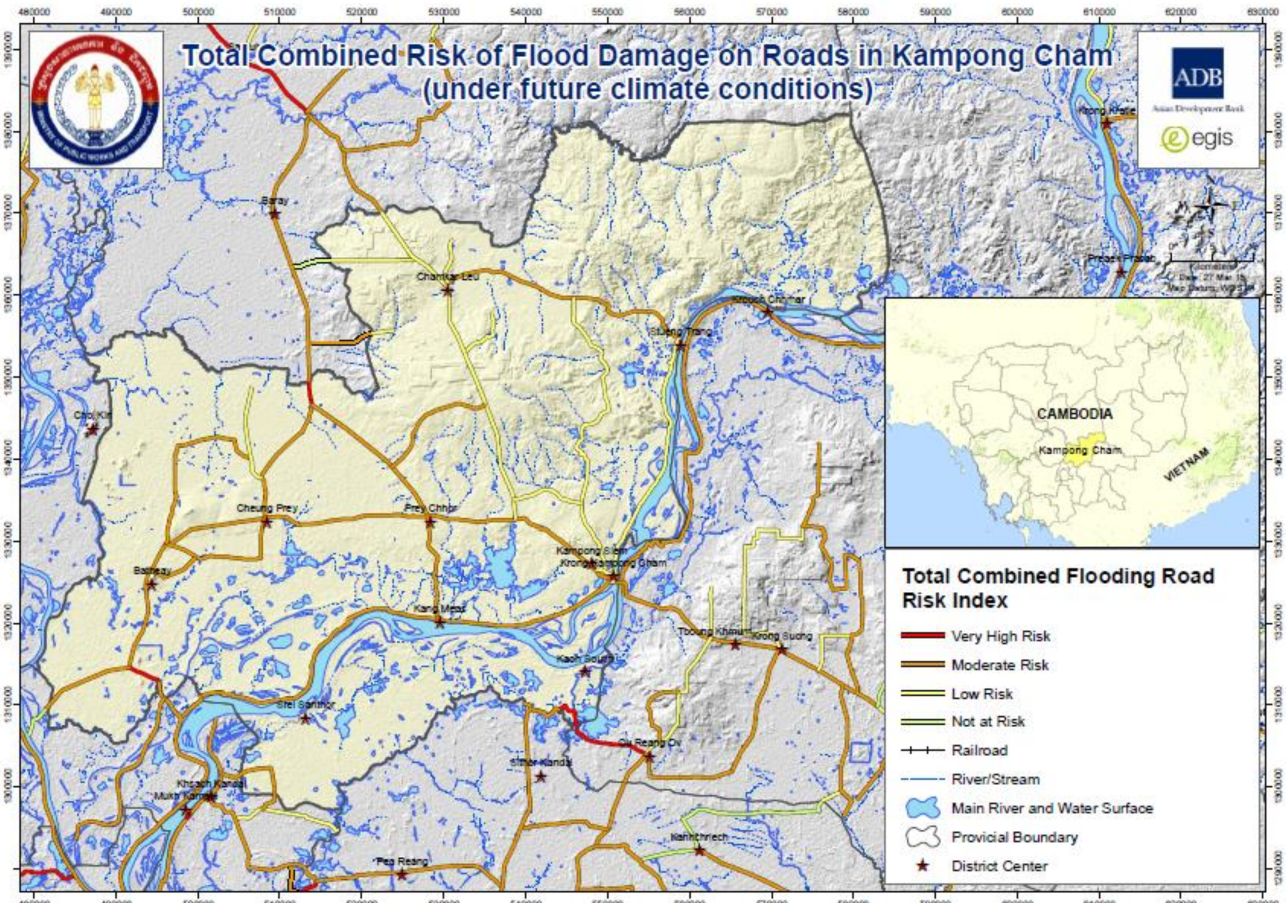


Figure 9-6 Total Combined Risk of Flooding Kampong Cham RCP 8.5 year 2055

9.11. Sihanoukville

168. Under future climate conditions year 2055 RCP 8.5 the area around Sihanoukville is classed as being at Moderate to High Risk. Due to the hilly area and large number of water courses this is due to flash floods. Sea level rise at this location is of the order 3mm/year.

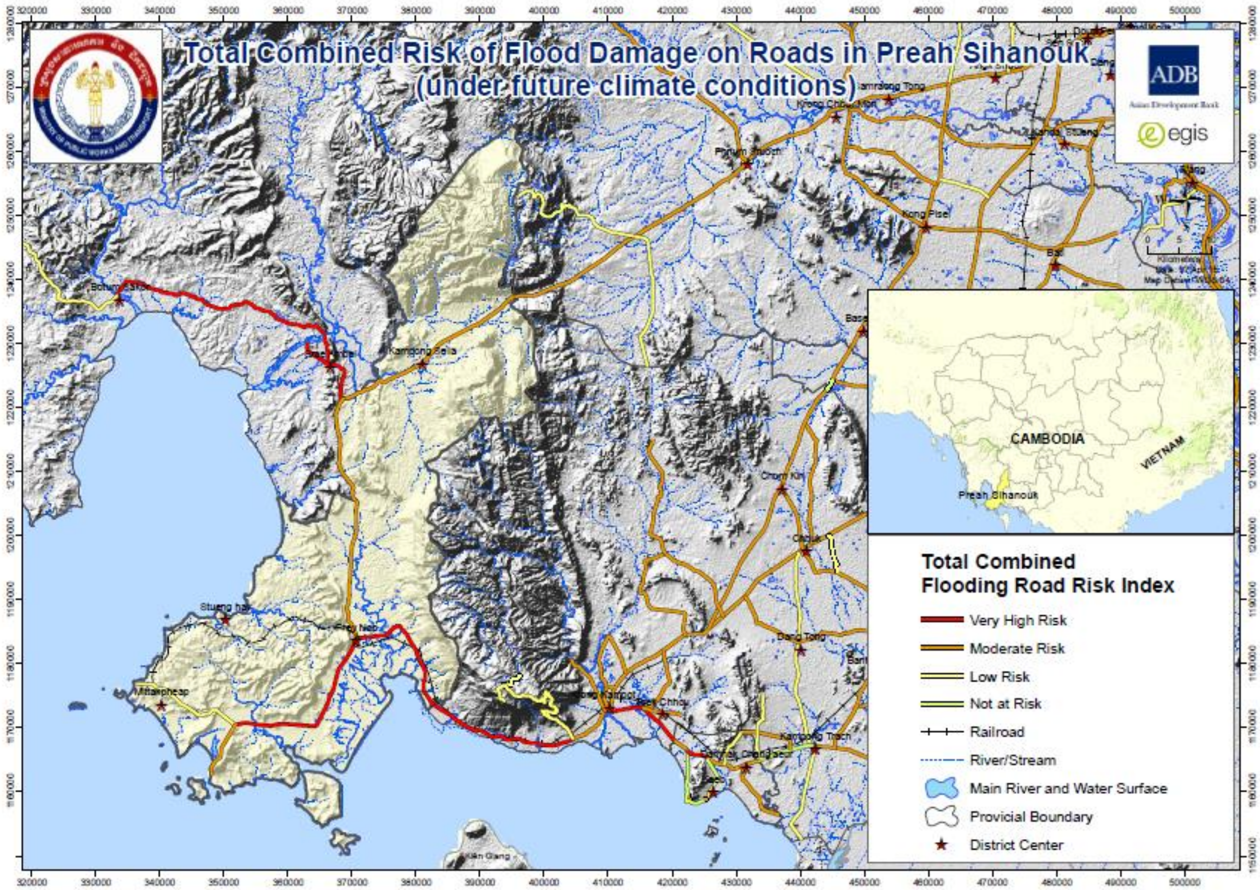


Figure 9-7 Total Combined Risk of Flooding Sihanoukville RCP 8.5 year 2055

9.12. Siem Reap

169. Under future climate conditions year 2055 RCP 8.5 the area around Siem Reap is classed as being at Moderate to High Risk. This location is influenced by the expansion and contraction of Tonle Sap.

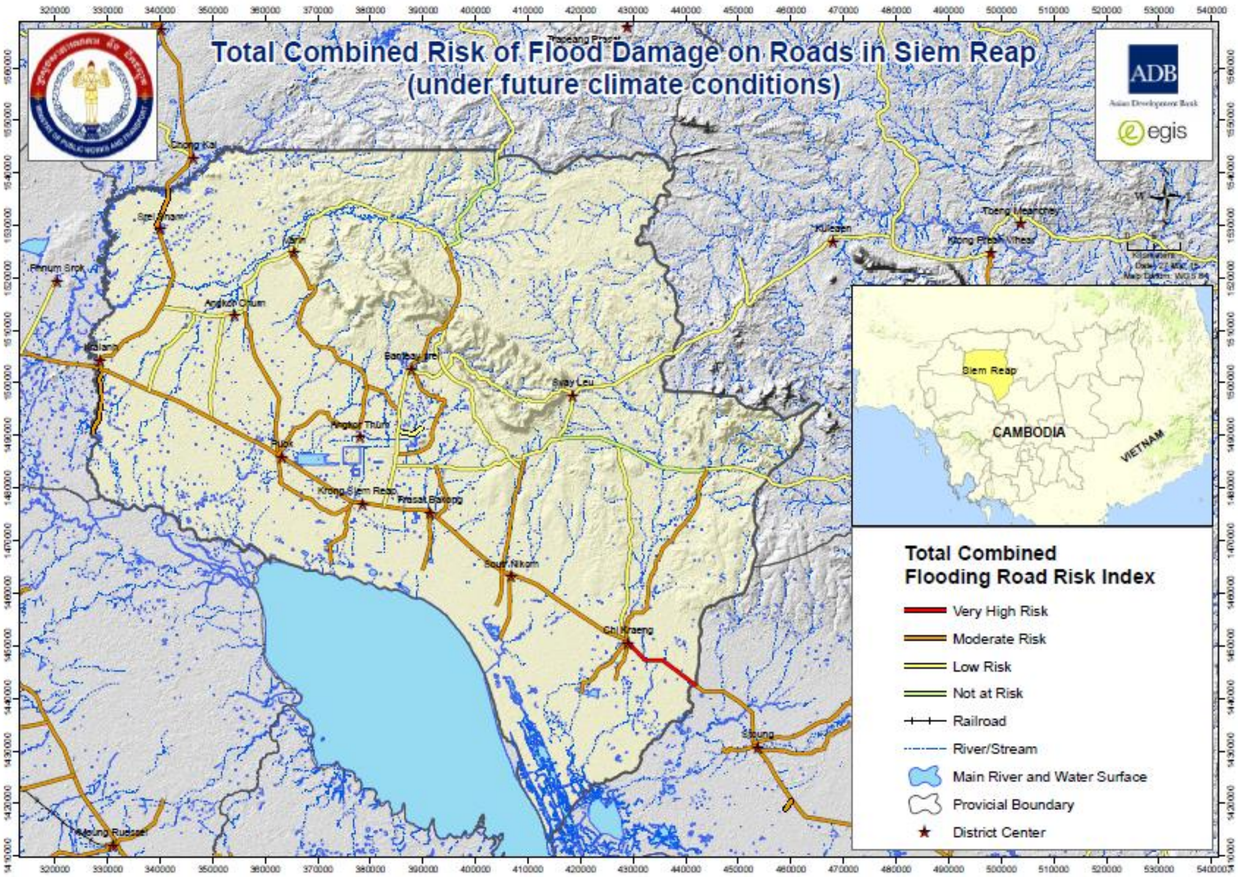


Figure 9-8 Total Combined Risk of Flooding Siem Reap RCP 8.5 year 2055

170. The implications of these risk maps are discussed in Chapter 11.

10. CLIMSYSTEMS

10.1. Introduction

171. This CRVA study examined the following locations

Table 10-1 Study location

Site name	Latitude	Longitude
Battambang	13.095	103.202
Kampong Cham	11.992	105.464
Siem Reap	13.367	103.844
PreahSihanouk	10.625	103.523

Figure 10-1 Location of the study sites

10.2. Rainfall Data

172. Daily observation for 25 years from MOWRAM was cross checked with other international data sources and provided the possible best data for this study. Other datasets were also checked to avoid potential errors in the data, including three international

datasets: MSQWEP[12] three hourly data, CHIRPS[13] daily data and Asian daily precipitation dataset. This cross checking confirmed that the local observation data is reasonably reliable. Therefore only the local observation data was used in the daily extreme precipitation analysis.

10.3. Temperature Data

173. Extreme temperature is calculated from global gridded datasets and may be not exactly the same as the local observation records. However it is adequate for risk assessment.

10.4. Supporting Data

174. Historical daily precipitation, maximum and minimum temperature, solar radiation data for SPEI calculations for study areas were extracted from the Global Meteorological Forcing Dataset for land surface modelling, 0.5 by 0.5 degree, from 1961-2012. (For information access: http://hydrology.princeton.edu/data.php.)

10.5. Methodologies

10.5.1. Extreme precipitation depth and duration

10.5.1.1. Historical DDF Development

175. A fundamental issue in the estimation of quantiles is the need to extrapolate to recurrence intervals significantly larger than the available records. This can be solved using regionalization, a standard practice for improving the estimation of event quantiles at sites with comparatively short records. In this report, the index regional flood frequency analysis method based on L-moments proposed by Hosking (Hosking and Wallis, 2005) is discussed to estimate the regional rainfall quantiles for the studied area.

Step 1: Derive the rainfall intensity time series of the different durations from historical hourly data time series. The durations include: 3, 6, 12, 24, 48, 72, 120, 144 and 168 hours, then select annual maxima series from the rainfall intensity series. Fit the annual maxima series for each duration to a group of probability distribution functions. Three distribution functions can be tested, including: Generalized Logistic (GLO), generalized extreme value (GEV), and Gumbel distribution[14]. Choose the method to deploy for distribution parameter estimation.

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[12] Multi-Source Quantile Weighted-Ensemble Precipitation. A method of predicing rainfall using a set of circulation models

[13] Climate Hazards Group InfraRed Precipitation with Station data. A global rainfall dataset which incorporates 0.05° resolution satellite imagery and in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.

[14] GLO, GEV and Gumbel distributions are statistical models for the prediction of extrme events

Step 2: Assess their goodness of fit with the Anderson-Darling test to follow the method (Vigione, 2008). The Anderson-Darling test measures the extent of the departure, in terms of probabilities, between a simulated hypothetical distribution and the frequency distribution for consideration. If the estimated probability is greater than some defined significance level, the test fails. Explore which of the three distributions, provides the best fit. For the purpose of illustration we continue with the presumption that GEV parameters are used for further analysis.

Step 3: Calculate rainfall depths for the range of return periods (including 2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 year) for each storm duration using GEV distribution parameters obtained from Step 1. The values consist of the table of depth-duration-frequency (DDF). The intensity-frequency-duration (IDF) table can be computed directly from the DDF table by simply dividing the rainfall depths by duration in hours.

Step 4: Generate the DDF and IDF curves based on the tables of DDF and IDF. A shape-preserving piecewise cubic interpolation is used to produce smooth DDF and IDF curves.

This is shown in Figure 10-2 below.

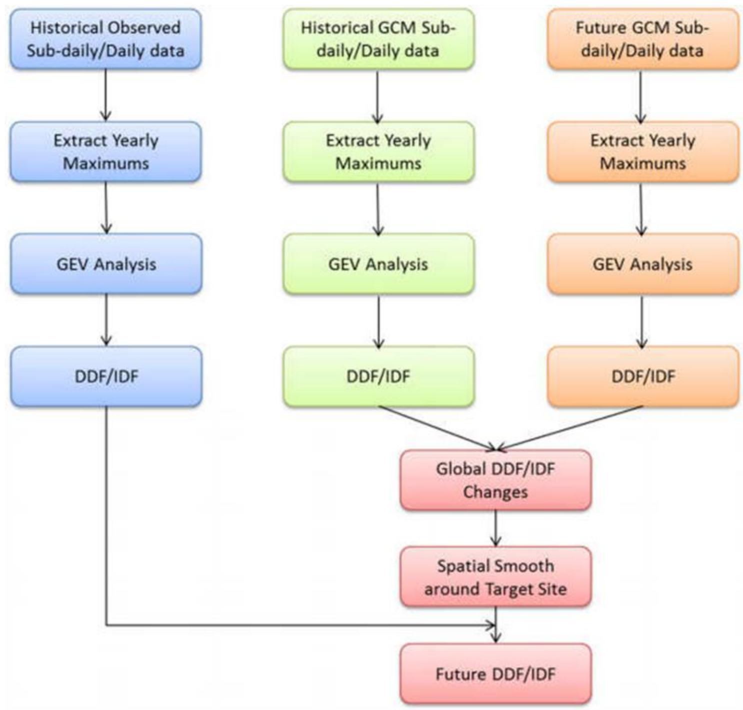

Figure 10-2 Equidistance quantile-matching method for generating future DDF curves under climate change.

10.5.1.2. Future DDF Development

176. The impacts of climate change on historical DDF and IDF are evaluated based on climate model data. In order to reduce uncertainty of climate change simulated by GCMs, the outputs of as many as possible of these GCMs should be used. According to the Fifth Assessment Report of IPCC (AR5), there are 42 GCM models developed by various research centres around the world. Currently, only 22 GCMs out of the 42 GCMs are validated because: i) Not all the GCMs generate selected RCPs for future climate scenarios (i.e., 4.5 and 8.5); and ii) there are some technical issues related to downloading (such as connection to remote servers or repositories) for some GCM models. Please see Table A1 Annex A for model details for sub-daily precipitation analysis.

177. The basic procedure is to employ an equidistant quantile matching (EQM) method to update the DDF and IDF curves under changing climate conditions.

Step 1: GCM 3 hourly output for each grid cell are analysed using extreme value analysis (EVA) to calculate extreme rainfall amounts for current climate (called the baseline, 1986-2005), and the future periods of interest.

Step 2: DDF and IDF change factors for the range of durations (3, 6, 12, 24, 48, and 72, 120, 144 and 168 hours) and return years (2, 3, 5, 10, 15, 25, 50, 100, 200 and 300 year) for each GCM under RCP4.5 and RCP8.5 (or other RCPs) can be calculated by applying a pattern scaling approach (Li and Ye, 2011).

Step 3: Interpolate the global DDF and IDF change patterns into the same spatial resolutions (0.5^o x 0.5^o) to construct a global database. Furthermore, a super ensemble method can be applied to derive ensemble statistics at different percentiles (e.g., 25th and 75th percentile of the GCM ensemble), with both RCP4.5 and RCP8.5 change factors for all GCMs being applied equally without any weighting.

Step 4: Project the historical estimated precipitation depth/intensity values of each duration and return period using the global DDF and IDF change factors for the studied area for selected future time periods (e.g. 2060 RCP8.5). The global DDF and IDF changes show high variability around the world. There are also considerable differences among GCM members. To further reduce the impact of natural variabilities, the change factors applied can be averaged over the studied region. Note: A single grid cell GCM/RCM change factor could cause serious bias to the final result. Hence the methodological need to take a more regional approach.

178. This approach is to perturb the change in extreme event changes, which is crucial for storm water management. Sørup et al. (2017) applied a similar IDF perturbation method, which is a promising way of creating artificially perturbed precipitation time series, which can represent a changed climate and be used as input in hydrologic and hydraulic models. The methodology perturbs existing time series based on a semi-Markov system where precipitation time series are split into events characterised as dry, extreme or non-extreme. The wet events are divided into different states based on an Intensity-Duration-Frequency relationship based on state selection criterion.

10.5.2. Short duration simple scaling methodology

179. This part is for the perturbation of short duration (<1.0 hour), which is very important for storm water design. However either no GCM data are available or it is construed to be less reliable. After the longer duration intensity and duration chart is formed, a log-log linear relationship could be calculated for different return periods (see figure 10-3). The slope of the linear equation could be applied for shorter durations to determine the intensity.

180. In this study log-log scaling factors were calculated from Multi-Source Weighted-Ensemble Precipitation (MSWEP), 3 hourly, 0.25*0.25 latitude longitude degree spatial resolution, 1979-2015 (http://www.gloh2o.org/). Then these factors were applied for sub-daily duration precipitation estimation.

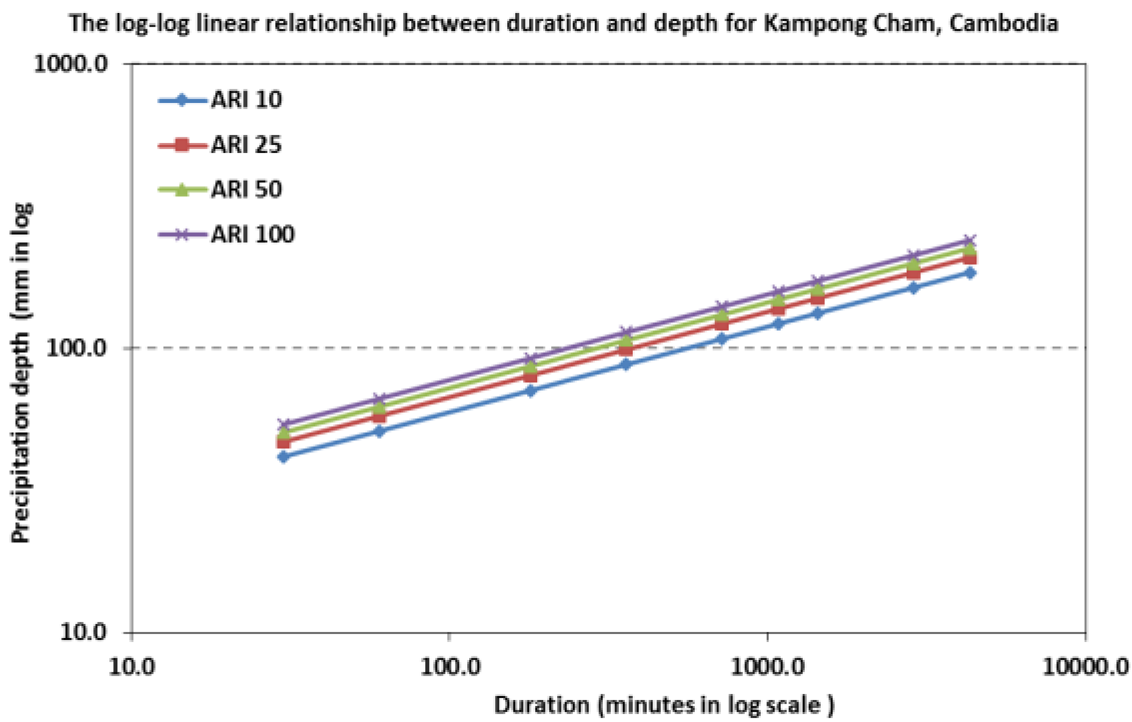

Figure 10-3 The log-log straight line relationship for Depth Duration Frequency (DDF)

181. The study of Agbazo et al. (2016) for rainfall intensities from ten rainfall stations showed that rainfall displayed scale invariance properties from 5 min to 1440 min. For time scaling, the statistical properties of rainfall followed the hypothesis of simple scaling. Therefore, a simple scaling model is thought to be a viable approach to estimate IDF curves of hourly and sub-hourly rainfall from rainfall projections. The obtained scaling exponents are less than 1 and range from 0.23 to 0.59.

182. The linearity of the moment from this study is also observed in others region of world. For example, Ghanmi (2014) in Tunisia (Northern of Africa) found that data from (Tunis) presented linearity, Ceresseti (2011) in France; Bara, et al. (2009) in Slovakia; Nhat (2006) in Japan, Bougadis and Admowski (2006) in Canada have found linearity in similar studies.

10.5.3. Extreme temperature analysis

183. Similar to extreme precipitation approach, daily extreme maximum temperature analysis applied generalized extreme values (GEV) analysis using L-moments method (Hosking and Wallis, 2005).

184. Historical daily maximum temperature data for the study areas were extracted from the Global Meteorological Forcing Dataset for land surface modelling, 0.25 by 0.25 degree, from 1961-2012. (For information access: http://hydrology.princeton.edu/data.php.)

10.6. Drought analysis

185. It is relevant to consider the Standard Precipitation Evapotranspiration Index (SPEI). Based upon precipitation and potential evapotranspiration data, an SPEI approach has the capacity to include the effects of temperature variability in drought risk assessments. SPEI is based on a water balance; it can be compared to the self-calibrated Palmer Drought Severity Index[15] (PDSI) developed by Serrano, Begueria and Moreno (Vicente-Serrano et al. 2010).The SPEI uses the monthly (or weekly) difference between precipitation and PET (Potential Evapotranspiration) which is a simple water balance methodology (based upon the work of Thornthwaite, 1948) that is calculated at different time scales to obtain the SPEI. A serially complete data set of both temperature and precipitation (daily, weekly or monthly) is needed to calculate the SPEI. The results of an SPEI calculation are represented as positive (wetter than normal) and negative (drier than normal) conditions. As drought is a key concern of this analysis an example of the SPEI number (0 to -0.99) and their relationship with the severity of drought being modelled and the return period likelihood per 100 years are provided in Table 10-2.

186. Historical daily precipitation, maximum and minimum temperature, solar radiation data for SPEI calculations for study areas were extracted from the Global Meteorological Forcing Dataset for land surface modelling, 0.5 by 0.5 degree, from 1961-2012. For information access: http://hydrology.princeton.edu/data.php.

Table 10-2 Dry Component of the SPEI and Sample Probability of Recurrence

SPEI	Category	# of times in 100 yrs.	Severity of event
0 to -0.99	Mild dryness	33	1 in 3 yrs.
-1.00 to-1.49	Moderate dryness	10	1 in 10 yrs.
-1.5 to -1.99	Severe dryness	5	1 in 20 yrs.
< -2.0	Extreme dryness	2.5	1 in 50 yrs.

10.7. GCMs and pattern scaling approach for climate change scenarios

187. Pattern scaling techniques have been widely used to provide climate change projections for time periods and emission scenarios that have not been simulated by GCMs. The assumption underlying these methods is that the local response of a climate variable is linearly related to the global mean temperature change, with the geographical pattern of change independent of the forcing (Mitchellet al., 1999, and Mitchell, 2003).Thus the anomaly in variable V, for a particular grid-box (i), month or season (j), year or period (y), and forcing scenario (x) is given by:

[15] An index of dryness using recent precipitation and temperature data

$\Delta Vxijy = \Delta Txy . V'ij$

where ΔT is the global mean temperature anomaly and V' is a fixed response pattern.

Climate change scenario data from the SimCLIM data package were used for this pattern scaling application and were applied to monthly temperature and precipitation data.

(For details, please visit: [http://documents.climsystems.com/news/6-11-2013/ SimCLIM_ 2013__AR5_data_manual.pdf](http://documents.climsystems.com/news/6-11-2013/SimCLIM_2013__AR5_data_manual.pdf))

188. The outputs of these 40 GCM models and 6 CORDEX RCM monthly ensemble median temperature and precipitation monthly change factors were used to derive the global mean temperature change figures given below.

Table 10-3 Global mean temperature changes applied in this study from a 40 GCM global ensemble of CMIP5[16] data.

RCP and time slice	Global mean temperature change (Celsius)
RCP8.5mid_2030,	0.94
RCP8.5mid_2050,	1.70

Under RCP 8.5 by 2030 global temperatures may have risen by 0.94°C and by 2050 by 1.70 °C.

These increments were used in for future drought analysis and long term rainfall analysis.

(See Annex A Table A2 and Table A3 for model details.)

10.8. Results of Climate Change Projections

10.9. 1. Results

1. The following parameters have been produced:

   1) Historical sub-daily or daily extreme precipitation intensity for 10, 25, 50, 100 year average return interval (ARI) and seasonal precipitation total

[16] Coupled Model Intercomparison Project. An ocean-atmosphere modelling system of the Working Group on Coupled Modelling (WGCM), overseen by the Joint Scientific Committee for the World Climate Research Program using data from about 30 coupled GCMs. Successive phases of the project include more realistic scenarios of climate forcing for both historical, paleoclimate and future scenarios. The most recent is the fifth phase - CMIP5.

2) Future (2030, 2050, RCP8.5 scenario) daily extreme precipitation intensity for 10, 25, 50, 100 year average return interval (ARI)
3) Historical sub daily or daily maximum temperature for 10, 25, 50, 100 year average return interval (ARI)
4) Future (2030, 2050, RCP8.5 scenario) sub daily or daily maximum temperature for 10, 25, 50, 100 year average return interval (ARI)
5) Historical severe and extreme drought frequency
6) Future (2030, 2050, RCP8.5 scenario) severe and extreme drought frequency

The results are given below.

10.9.1. Rainfall

Table 10-4 Extreme Precipitation Depth Duration tables for Cambodia sites

Battambang									
ARI	Duration (minutes)								
	30	60	180	360	720	1080	1440	2880	4320
	Baseline								
10	31.4	38.7	53.8	66.3	81.6	92.1	100.4	123.7	139.7
25	33.6	41.4	57.6	70.9	87.3	98.6	107.4	132.3	149.4
50	34.9	43.0	59.7	73.6	90.6	102.3	111.5	137.3	155.0
100	35.9	44.2	61.5	75.7	93.2	105.2	114.7	141.2	159.5
	2030								
10	32.9	40.5	56.3	69.1	85.0	96.0	104.3	128.0	144.4
25	35.5	43.7	60.7	74.5	91.6	103.5	112.5	137.9	155.7
50	37.1	45.6	63.4	77.8	95.7	108.1	117.5	144	162.6
100	38.4	47.2	65.7	80.6	99.1	111.9	121.7	149.1	168.4
	2050								
10	34.0	41.9	58.2	71.4	87.7	99.0	107.4	131.5	148.2
25	37.0	45.5	63.3	77.5	95.2	107.5	116.6	142.5	160.8
50	38.8	47.8	66.4	81.3	99.8	112.7	122.4	149.4	168.7
100	40.4	49.7	69.1	84.5	103.8	117.3	127.4	155.4	175.6

Kampong Cham									
ARI	Duration (minutes)								
	30.0	60.0	180.0	360.0	720.0	1080.0	1440.0	2880.0	4320.0
	Baseline								
10.0	41.6	51.2	71.2	87.7	107.9	121.9	132.9	163.6	184.8
25.0	46.9	57.8	80.4	98.9	121.8	137.6	150.0	184.6	208.5
50.0	50.6	62.3	86.6	106.7	131.3	148.3	161.7	199.0	224.8
100.0	54.0	66.5	92.4	113.8	140.1	158.2	172.5	212.4	239.9
	2030								
10.0	43.4	53.4	74.2	91.2	112.1	126.6	137.6	169.0	190.8
25.0	49.4	60.8	84.5	103.7	127.5	144.0	156.6	192.1	216.9
50.0	53.6	66.0	91.7	112.5	138.3	156.2	169.9	208.3	235.3
100.0	57.6	70.9	98.6	120.8	148.5	167.7	182.4	223.6	252.8
	2050								
10.0	44.8	55.1	76.7	94.0	115.5	130.5	141.5	173.4	195.6
25.0	51.3	63.2	87.9	107.6	132.2	149.3	162.0	198.2	223.7
50.0	56.0	68.9	95.9	117.3	143.9	162.6	176.6	215.8	243.8
100.0	60.5	74.4	103.5	126.5	155.2	175.3	190.5	232.8	263.2

Siem Reap									
	Duration (minutes)								
ARI	30.0	60.0	180.0	360.0	720.0	1080.0	1440.0	2880.0	4320.0
	Baseline								
10.0	49.5	60.9	84.7	104.3	128.4	145.0	158.1	194.6	219.8
25.0	61.1	75.2	104.6	128.8	158.6	179.1	195.2	240.4	271.4
50.0	70.6	86.9	120.9	148.8	183.2	206.9	225.6	277.7	313.6
100.0	80.8	99.5	138.4	170.3	209.7	236.8	258.2	317.9	359.0
	2030								
10.0	51.7	63.6	88.5	108.7	133.7	151.0	164.1	201.4	227.2
25.0	64.4	79.3	110.2	135.4	166.4	188.0	204.4	250.6	282.9
50.0	74.9	92.2	128.2	157.4	193.5	218.6	237.8	291.3	328.9
100.0	86.3	106.2	147.7	181.2	222.9	251.7	274.0	335.6	379.1
	2050								
10.0	53.4	65.8	91.5	112.2	137.9	155.8	169.0	206.9	233.2
25.0	67.1	82.6	114.8	140.7	172.8	195.2	211.9	259.0	292.2
50.0	78.4	96.5	134.2	164.3	201.9	228.0	247.6	302.4	341.3
100.0	90.7	111.7	155.3	190.0	233.6	263.8	286.8	350.0	395.3

Sihanouk ville									
	Duration								
ARI	30.0	60.0	180.0	360.0	720.0	1080.0	1440.0	2880.0	4320.0
	Baseline								
10.0	56.3	69.3	96.3	118.6	146.0	164.8	179.7	221.2	249.9
25.0	63.1	77.7	108.1	133.1	163.8	185.0	201.7	248.3	280.4
50.0	67.7	83.3	115.8	142.6	175.5	198.3	216.1	266.1	300.5
100.0	71.7	88.3	122.8	151.1	186.1	210.1	229.1	282.0	318.5
	2030								
10.0	58.7	72.3	100.5	123.4	151.7	171.4	186.2	228.6	257.9
25.0	66.5	81.8	113.8	139.6	171.6	193.8	210.6	258.3	291.7
50.0	71.7	88.3	122.8	150.5	184.9	208.8	227.0	278.4	314.4
100.0	76.5	94.2	131.0	160.4	197.1	222.6	242.0	296.7	335.3
	2050								
10.0	60.7	74.7	103.9	127.3	156.4	176.6	191.5	234.5	264.4
25.0	69.2	85.2	118.4	144.8	177.8	200.9	217.8	266.4	300.8
50.0	75.0	92.3	128.4	156.9	192.5	217.4	235.7	288.3	325.6
100.0	80.4	99.0	137.7	168.0	206.0	232.6	252.4	308.6	348.9

Table 10-5 Monthly precipitation changes for 4 sites in Cambodia (% per degree global warming)

Battambang monthly precipitation													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Baseline (mm)	5.10	19.10	42.20	88.50	134.70	139.40	157.20	172.90	230.10	238.20	56.20	7.70	1292.30
Median (50%)	5.41	6.55	4.13	0.70	1.34	2.12	1.09	1.20	2.61	5.29	9.82	21.23	3.17
Low Percent (10%)	-13.71	22.72	-11.60	-15.79	-10.51	-9.66	-5.78	-8.90	-2.69	4.49	9.15	-7.32	-7.63
High Percent (90%)	60.60	62.14	47.42	14.08	11.45	9.85	9.15	10.98	9.40	19.82	24.51	67.93	15.73

Kampong Cham monthly precipitation													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Baseline (mm)	12.40	18.90	57.40	105.50	173.10	185.30	193.40	188.90	281.60	201.30	60.80	17.30	1497.90
Median (50%)	3.19	0.25	2.37	4.97	0.50	2.55	2.89	1.47	1.96	3.84	4.81	12.63	1.79
Low Percent (10%)	-12.41	18.75	-18.00	-18.57	-11.30	-9.77	-4.65	-7.65	-2.53	5.00	9.61	-7.04	-8.17
High Percent (90%)	34.14	55.22	39.31	17.22	15.25	8.71	10.64	12.00	9.95	15.49	18.03	50.46	14.56

Siem Reap monthly precipitation													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Baseline (mm)	5.00	4.30	23.10	54.40	143.50	225.50	228.40	200.70	291.70	210.70	46.50	9.70	1446.50
Median (50%)	7.90	8.21	4.69	0.14	0.92	1.96	1.73	1.29	3.01	5.03	10.41	23.10	2.59
Low Percent (10%)	-20.29	22.81	-12.23	-15.70	-14.62	-8.62	-5.73	-7.56	-1.27	5.05	9.46	-4.30	-7.20
High Percent (90%)	52.62	55.12	41.14	13.25	10.26	9.63	9.73	14.11	10.26	26.62	24.16	67.94	14.49

Sihanoukville monthly precipitation													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Baseline (mm)	26.00	24.00	75.00	133.40	266.40	413.50	522.10	516.10	485.90	273.90	110.60	35.20	2886.10
Median (50%)	9.32	3.78	0.32	2.10	0.79	0.85	2.02	2.28	0.81	2.00	1.90	11.73	1.25
Low Percent (10%)	-14.33	15.46	-20.71	-14.60	-11.74	-8.74	-8.49	-7.38	-5.62	4.42	11.96	-9.45	-8.74
High Percent (90%)	40.71	40.80	51.26	27.87	15.83	11.60	8.37	12.75	7.42	11.19	18.29	43.20	13.64

Change percentages have not been scaled to table 10-3 changes in global mean temperature for 2030 and 2050. Therefore for 2030 all results need to be multiplied by 0.94 and for 2050 multiply by 1.7.

10.9.2. Drought Index

Table 10-6 Relative drought change in Cambodia sites

Site	Scenario	Severe Dry(%)	Extreme Dry(%)
Battambang	Baseline	3.47	1.26
Battambang	2030	5.93	2.16
Battambang	2050	7.51	3.83
Kampong Cham	Baseline	2.95	2.65
Kampong Cham	2030	3.83	4.02
Kampong Cham	2050	4.73	5.38
Siem Reap	Baseline	3.80	2.24
Siem Reap	2030	4.54	2.92
Siem Reap	2050	5.06	3.44
Sihanoukville	Baseline	3.12	2.57
Sihanoukville	2030	3.74	4.29
Sihanoukville	2050	4.73	5.41

10.9.1. Temperature

Table 10-7 Daily extreme high temperature for Cambodia sites

	Scenario	ARI			
Sites		10	25	50	100
Battambang	Baseline	44.8	45.8	46.5	47.2
Battambang	2030	45.8	46.7	47.5	48.2
Battambang	2050	46.8	47.9	48.7	49.4
Kampong Cham	Baseline	43.7	44.5	45.0	45.4
Kampong Cham	2030	44.9	45.8	46.3	46.7
Kampong Cham	2050	46.0	46.8	47.2	47.6
Siem Reap	Baseline	44.8	45.7	46.4	47.0
Siem Reap	2030	45.9	46.8	47.5	48.1
Siem Reap	2050	47.0	48.1	48.8	49.5
Sihanoukville	Baseline	41.4	42.3	42.9	43.5

Sihanoukville	2030	42.3	43.2	43.8	44.3
Sihanoukville	2050	43.1	44.0	44.6	45.2

11. Climate Change Impacts

11.1. Rainfall 30 minutes to 3 days

2. Extreme rainfall has been calculated for time durations of 30 minutes up to 4,320 minutes or 72 hours or 3 days. The frequency of occurrence of the rain fall is an important parameter and precipitation for Annual Return Intervals (ARI) of 10, 25, 50 and 100 years is given.

3. The baseline, or current situation is given, then two projected scenarios. These are based on RCP8.5 for the years 2030 and 2050. The results are shown below.

11.1.1. Battambang

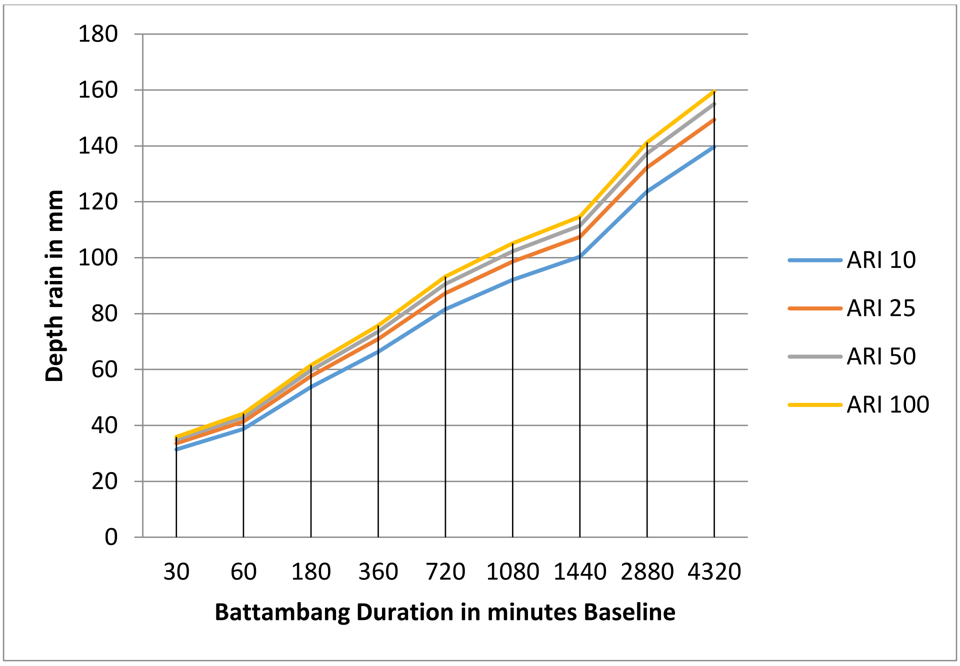

Figure 11-1 Depth of Rainfall versus Duration Baseline Battambang

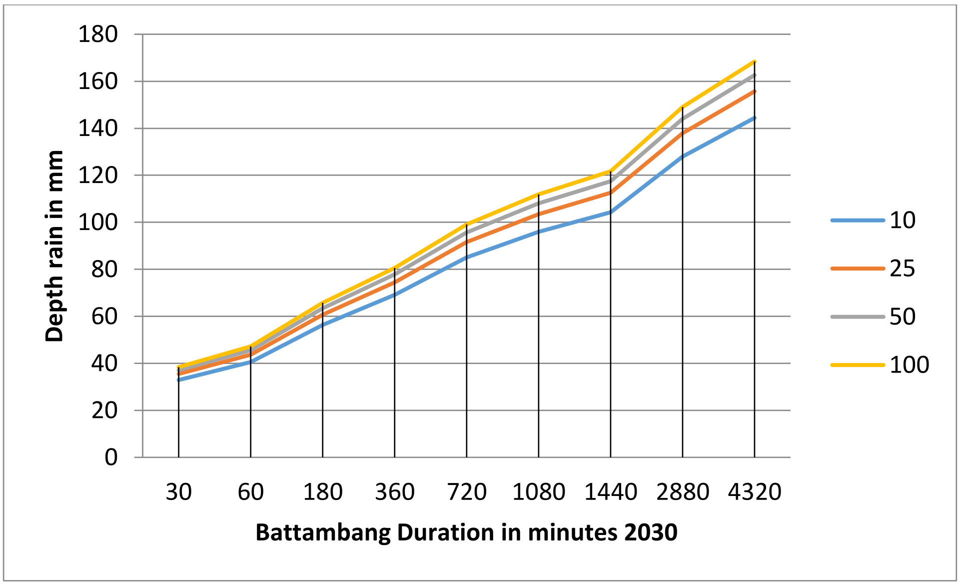

Figure 11-2 Depth of Rainfall versus Duration 2030 Battambang

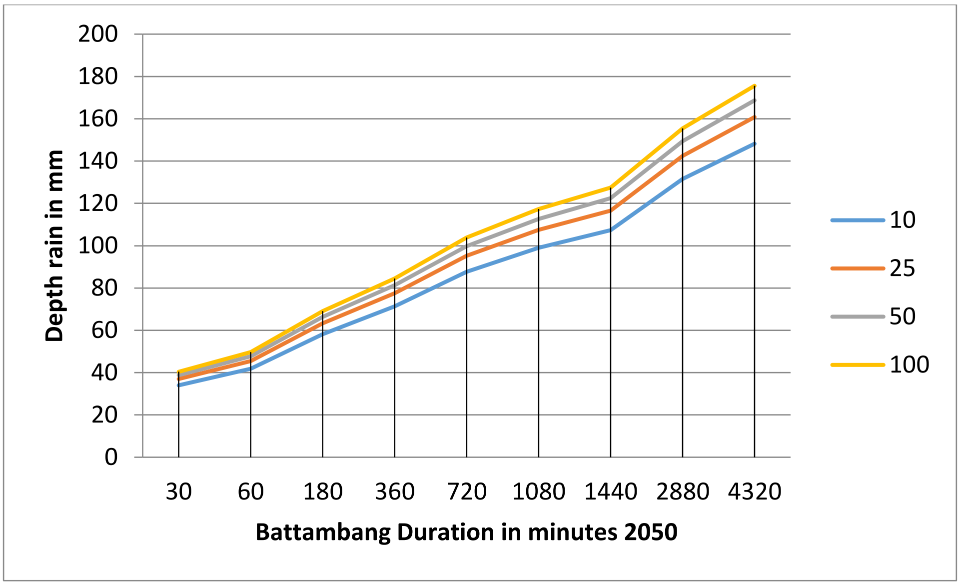

Figure 11-3 Depth of Rainfall versus Duration 2050 Battambang

11.1.2. Kampong Cham

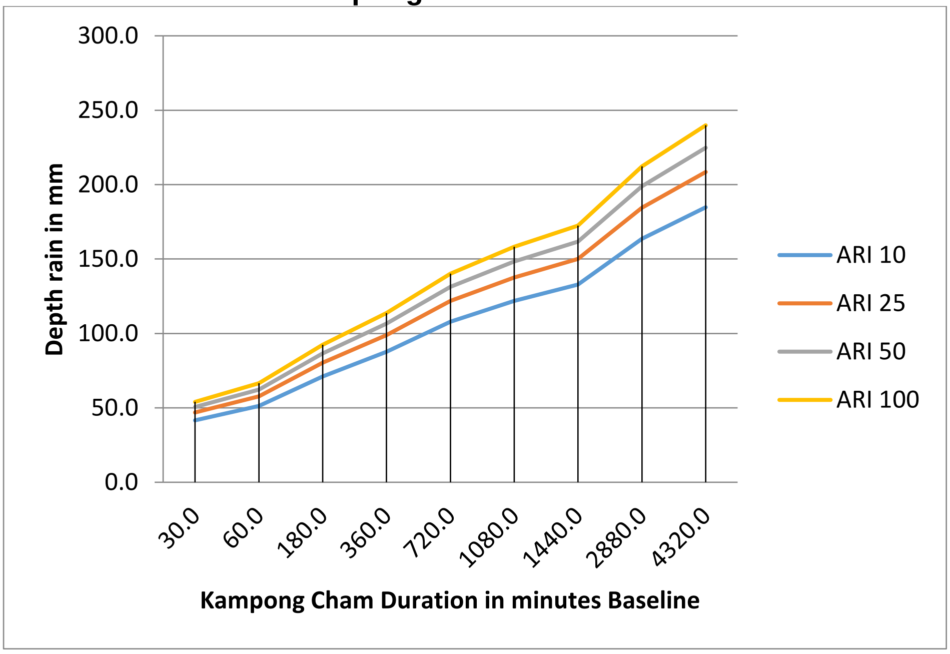

Figure 11-4 Depth of Rainfall versus Duration Baseline Kg Cham

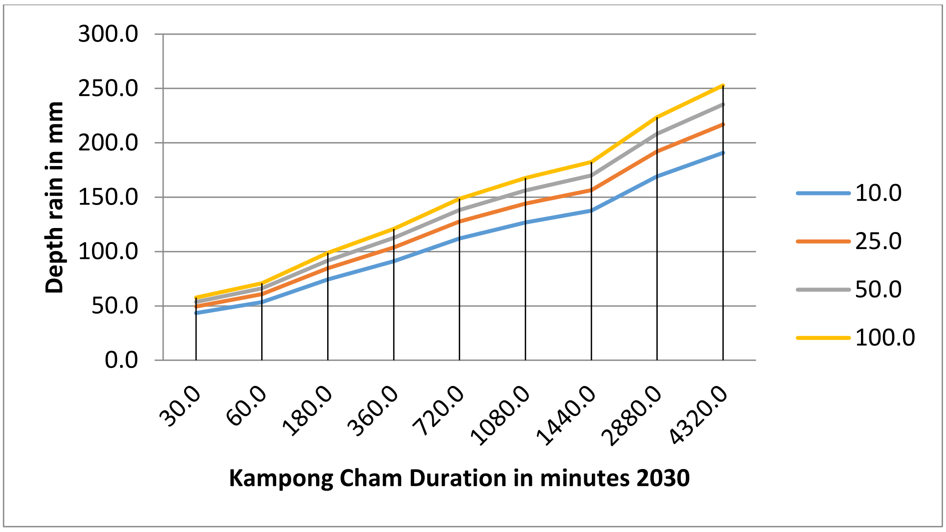

Figure 11-5 Depth of Rainfall versus Duration 2030 Kg Cham

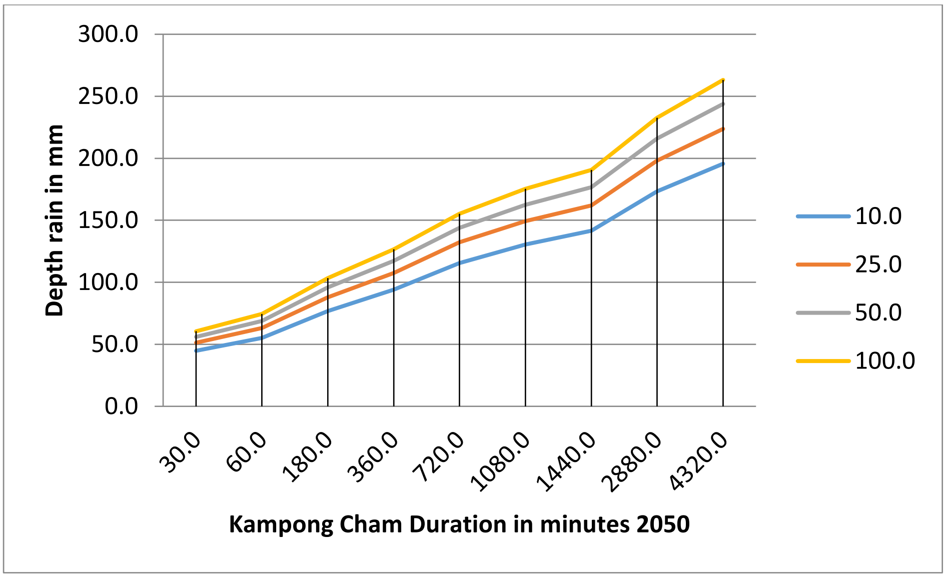

Figure 11-6 Depth of Rainfall versus Duration 2050 Kg Cham

11.1.3. Sihanoukville

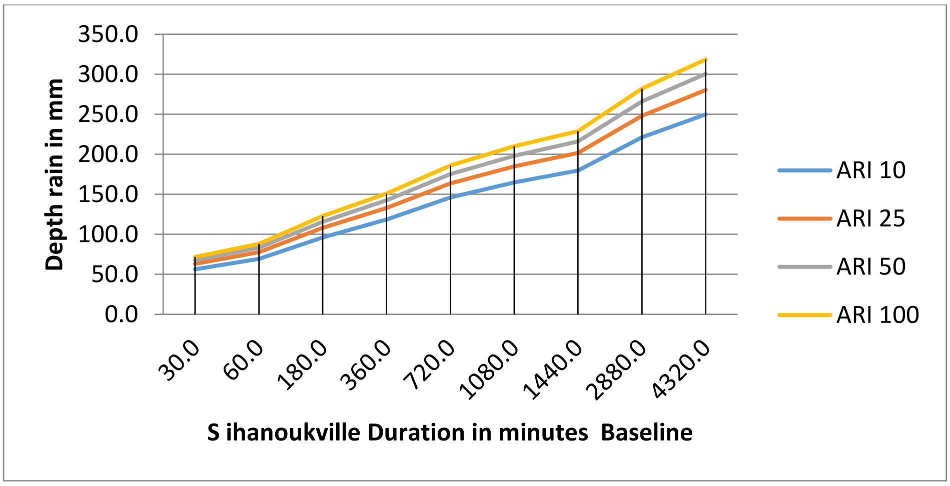

Figure 11-7 Depth of Rainfall versus Duration Baseline Sihanoukville

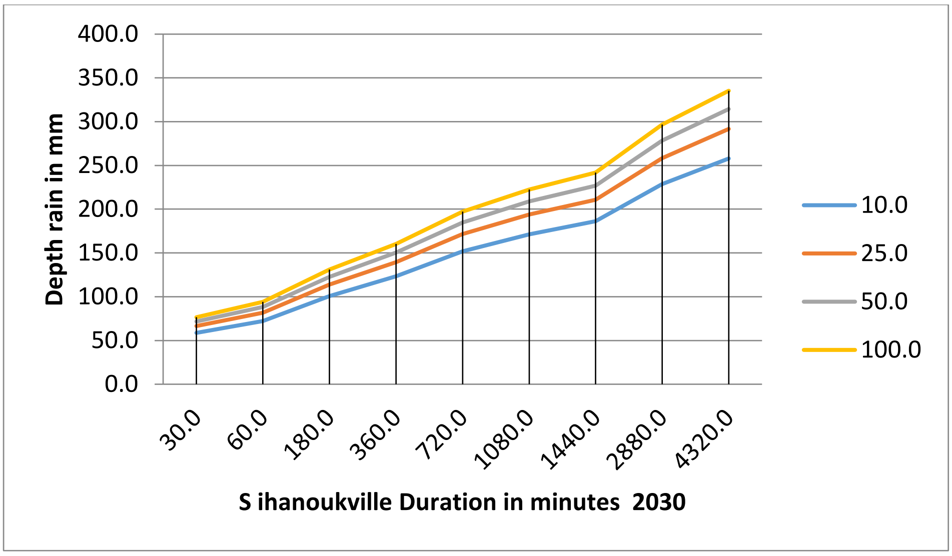

Figure 11-8 Depth of Rainfall versus Duration 2030 Sihanoukville

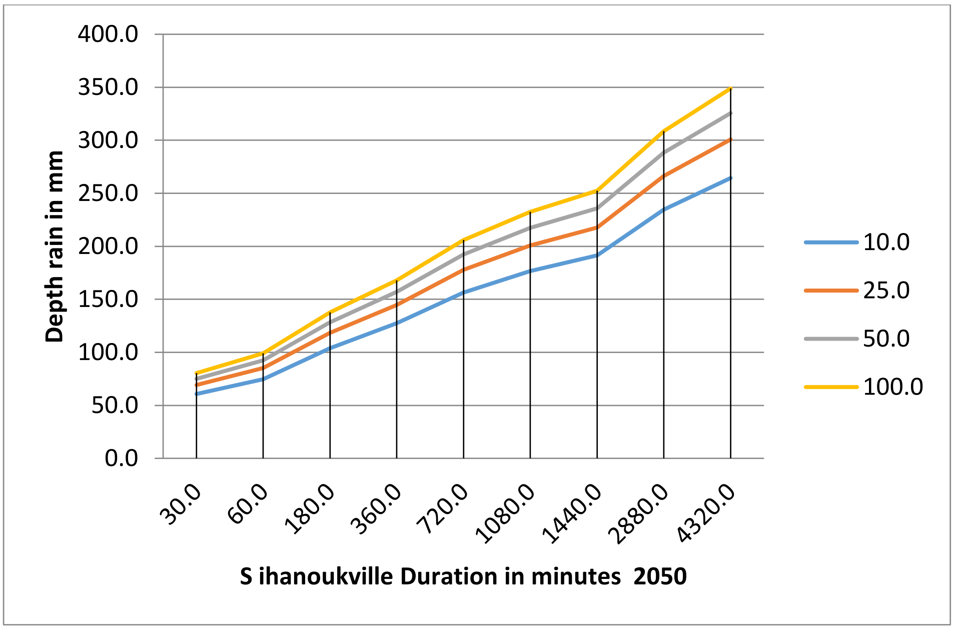

Figure 11-9 Depth of Rainfall versus Duration 2050 Sihanoukville

11.1.1. Siem Reap

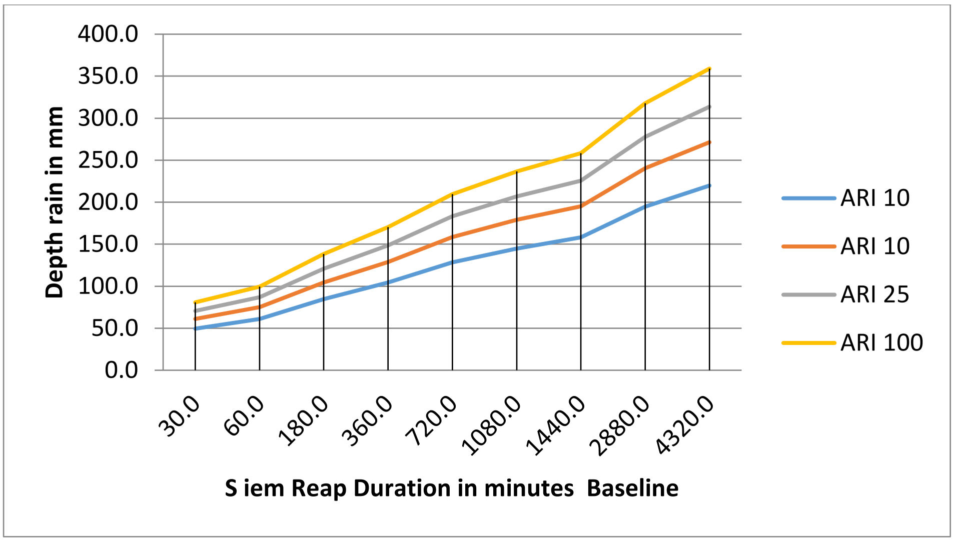

Figure 11-10 Depth of Rainfall versus Duration Baseline Siem Reap

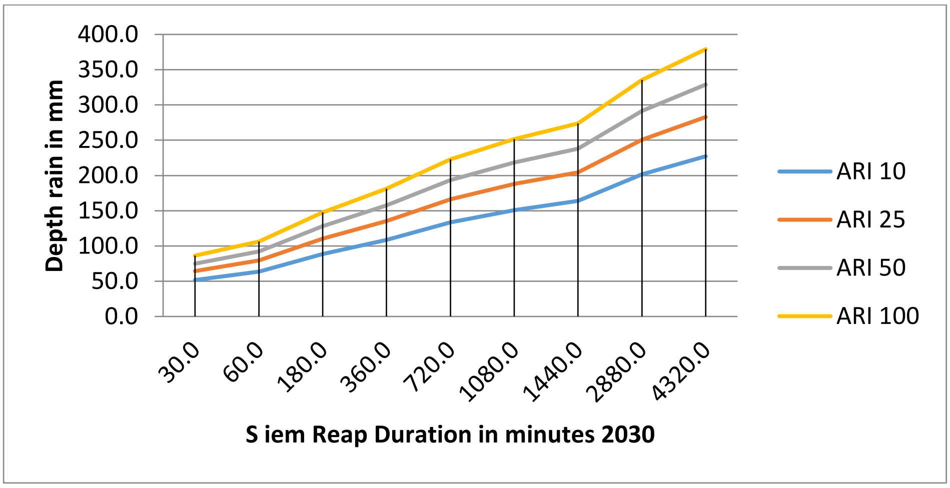

Figure 11-11 Depth of Rainfall versus Duration 2030 Siem Reap

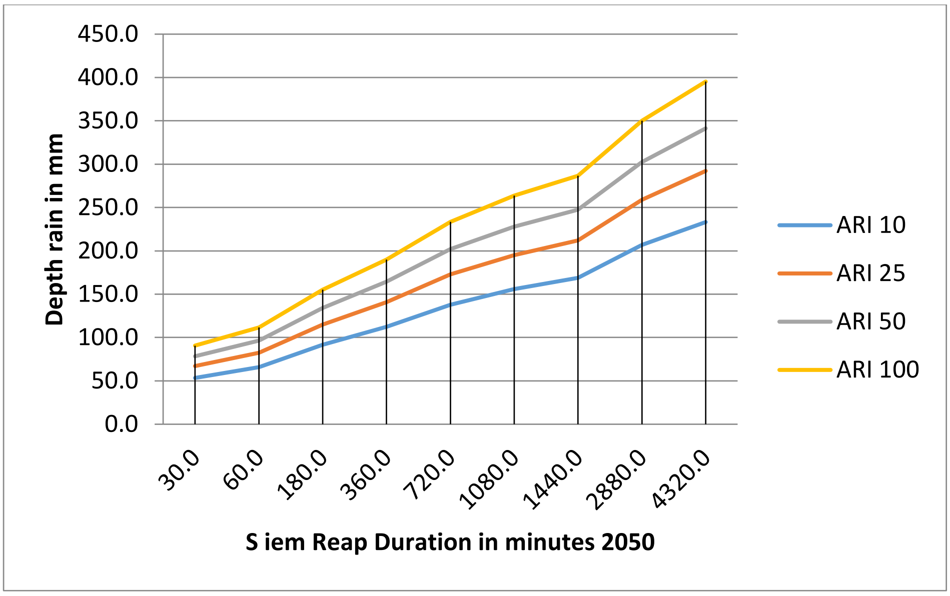

Figure 11-12 Depth of Rainfall versus Duration 2050 Siem Reap

4. As can be seen in all graphs the major divergence occurs at the higher ARI numbers in 2050.

11.2. Rainfall Duration 60 minutes

5. The above graphs show rainfall over a large duration from half an hour to 72 hours. For engineering design purposes the most common parameter is the 1 hour rainfall figure. Sometimes a 30 minutes or even 15 minutes figure is used if the historical rain fall data includes such short time periods. This is uncommon and in fact the most usual rainfall records are 24 hourly, as in this case.

6. Empirical evidence suggests that in extreme weather events the 1 hour rainfall figure represents 20% - 40% of the daily rainfall. Therefore the 1 hour figure, and any changes in it due to climate change, is a useful indicator. The following graphs are based on the extracted 60 minutes figures.

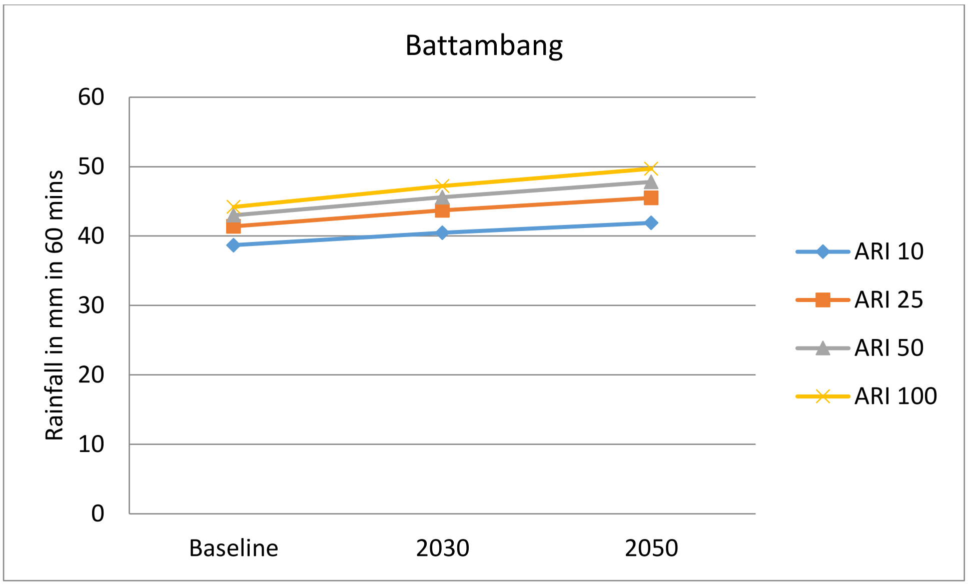

Figure 11-13 Depth of Rainfall in 1 hour Battambang

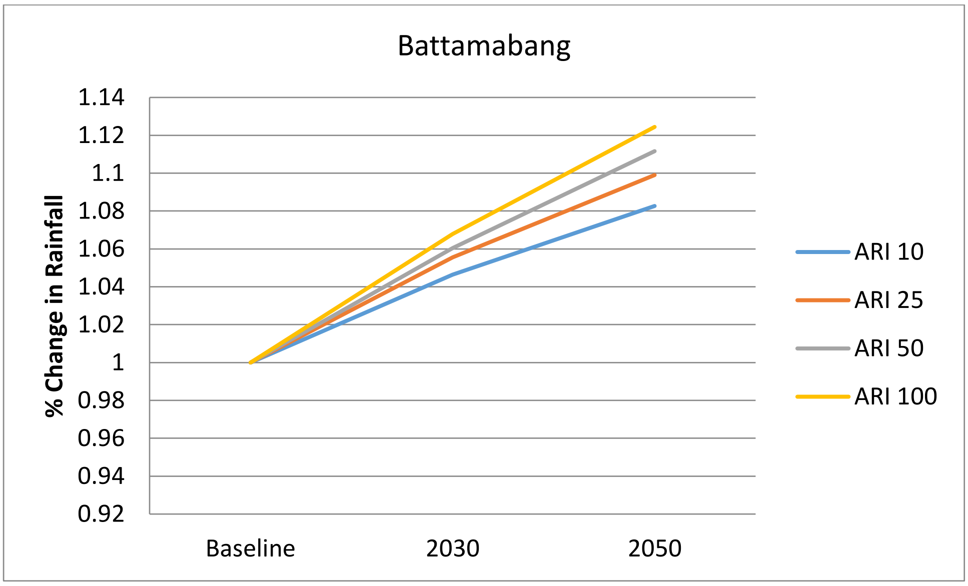

Figure 11-14 Change in Depth of Rainfall in 1 hour Battambang

7. The 1 in 10 year event is the most commonly used descriptor for urban drainage design. In Battambang by 2030 under RCP 8.5 there will be a 4 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 8% increase in 1 hour rainfall intensity.

8. If one takes the 1 in 100 year event as the extreme value figure then in Battambang by 2030 under RCP 8.5 there will be a 6 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 12% increase in 1 hour rainfall intensity.

9. A 12% increase in rainfall intensity is considered significant.

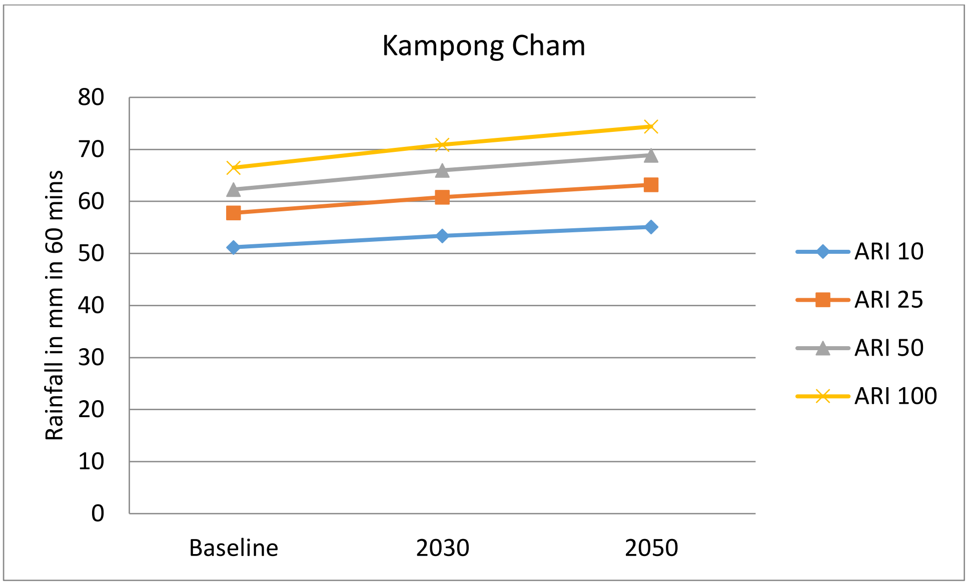

Figure 11-15 Depth of Rainfall in 1 hour Kampong Cham

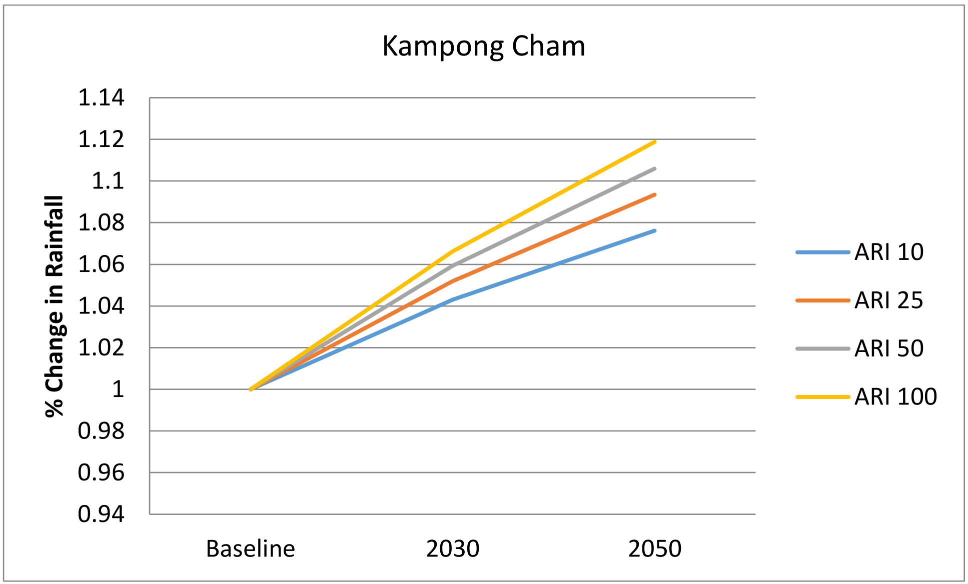

Figure 11-16 Change in Depth of Rainfall in 1 hour Kampong Cham

10. The 1 in 10 year event for Kampong Cham shows that by 2030 under RCP 8.5 there will be a 4 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 7% increase in 1 hour rainfall intensity.

11. The 1 in 100 year event for Kampong Cham shows that by 2030 under RCP 8.5 there will be a 7 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 11% increase in 1 hour rainfall intensity.

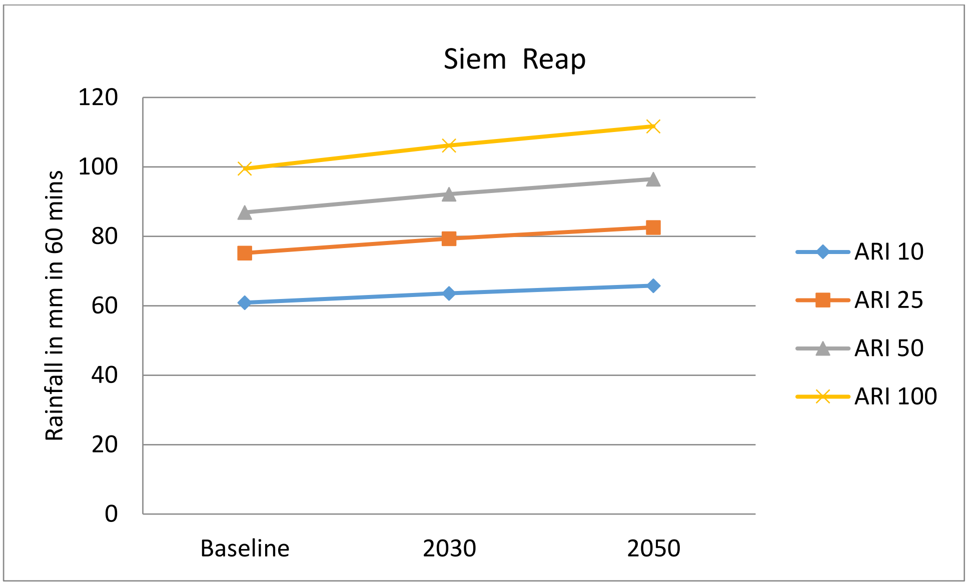

Figure 11-17 Depth of Rainfall in 1 hour Siem Reap

Figure 11-18 Change in Depth of Rainfall in 1 hour Siem Reap

12. Taking the 1 in 10 year event in Siem Reap by 2030 under RCP 8.5 there will be a 4 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 8% increase in 1 hour rainfall intensity.

13. Taking the 1 in 100 year event as the extreme value figure then in Siem Reap by 2030 under RCP 8.5 there will be a 7 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 12% increase in 1 hour rainfall intensity.

14. A 12% increase in rainfall intensity is considered significant.

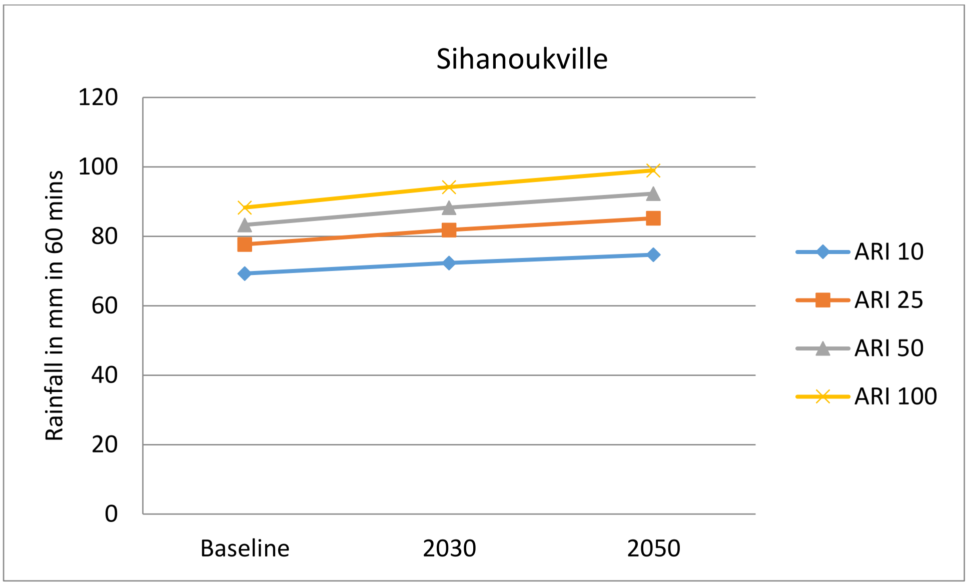

Figure 11-19 Depth of Rainfall in 1 hour Sihanoukville

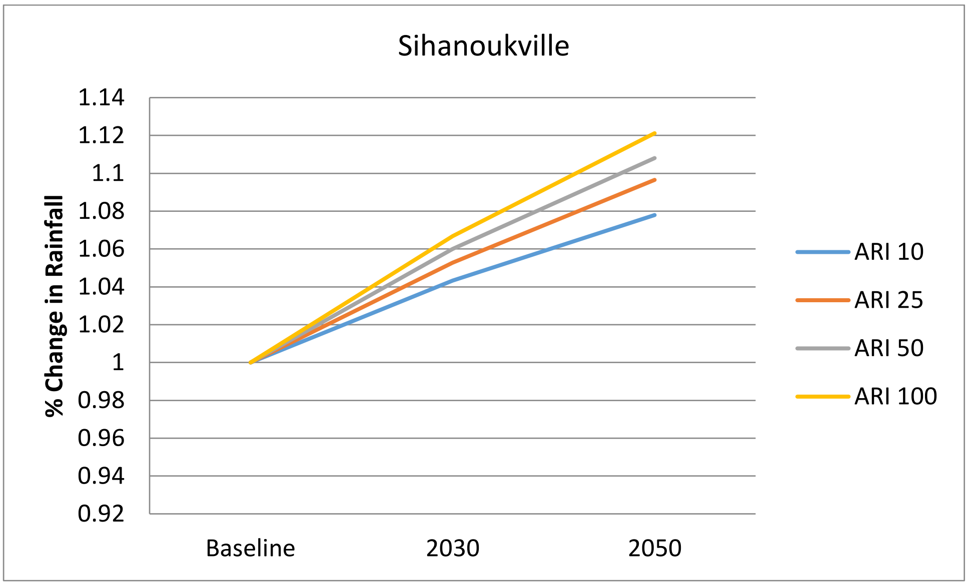

Figure 11-20 Change in Depth of Rainfall in 1 hour Sihanoukville

15. Taking the 1 in 10 year event in Sihanoukville by 2030 under RCP 8.5 there will be a 4 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 7% increase in 1 hour rainfall intensity.

16. Taking the 1 in 100 year event as the extreme value figure then in Sihanoukville by 2030 under RCP 8.5 there will be a 7 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 12% increase in 1 hour rainfall intensity.

17. A 12% increase in rainfall intensity is considered significant.

18. There is no geographical variation in likely increases in short term rainfall intensity across Cambodia. This does not mean that the rainfall is the same everywhere but that the increase for 1 in 10 year events and 1 in 100 year events under RCP 8.5 in 2030 and 2050 are around 4% and 12% in all four sites.

11.3. Drought

19. Drought is a complex natural phenomenon without a general and commonly accepted definition. In contrast to other extreme events such as floods, which are typically restricted to small regions and well-defined temporal intervals, droughts are difficult to pinpoint in time and space, affecting wide areas over long periods of time. It is very difficult to isolate the beginning of a drought, as drought development is slow and very often the drought is not recognized until human activities, or the environment, are affected. Moreover, the effects of a drought can persist over many years after it has ended.

20. Drought is an important parameter in Cambodia, particularly for farmers, as extended periods of drought can only be mitigated by additional irrigation.

21. It is very difficult to objectively quantify their characteristics in terms of intensity, magnitude, duration and spatial extent. We identify a drought by its effects at different levels, but there is not a physical variable we can measure to quantify droughts. Given the large difficulties to objectively quantify their characteristics (duration, intensity, magnitude, spatial extent, onset, etc.) several drought indices have been developed in the last decades (Heim, 2002: Bulletin of the American Meteorological Society, 83: 1149-1165) At present the two most widely used drought indices are:

- Palmer Drought Severity Index (PDSI Palmer 1965) - Based on a simplified water balance equation. Incorporates prior precipitation, moisture supply, runoff and evaporation demand at the surface level
- Standardised Precipitation Index (SPI McKee et al. 1993) - Based on precipitation anomalies

22. A critical issue in the study of the drought impacts is the multi-scalar nature of drought, since the response of the hydrological (soil moisture, groundwater, river discharge, reservoir storage, etc) and biological (crops, natural vegetation, etc) systems to water shortage varies markedly and have different response times. This explains why severe drought conditions can be recorded in one system (e.g., low river flows) whereas other systems in the same region (e.g., crops) have normal or even humid conditions.

23. The SPI calculation is based on two assumptions:

- the variability of precipitation is much higher than that of other variables, such as temperature and potential evapotranspiration (PET)
- the other variables (PET) are stationary i.e. they have no temporal trend.

24. This assumes droughts are controlled by the time wise changes in precipitation. However, temperature can have a marked effect on drought conditions. The general temperature increase (0.5-2°C) during the last past 150 years and the increase predicted by climate change models during the 21st century (IPCC, 2007) are expected to have dramatic consequences on drought conditions, with an increase in water demand due to evapotranspiration (Sheffield and Wood, 2008; Dubrovsky et al., 2008). The use of drought indices which include temperature data in their formulation (such as the PDSI) is preferable, especially for

applications involving future climate scenarios. However, the PDSI lacks the multi-scalar character essential for both assessing drought in relation to different hydrological systems, and differentiating among different drought types.

25. A drought index should be based on precipitation and PET and combine the sensitivity of PDSI to changes in evaporation demand with the multi-temporal nature of the SPI. The index must be suited to detecting, monitoring and exploring the consequences of global warming on drought conditions. This new drought index is the Standard Precipitation Evapotranspiration Index (SPEI). The SPEI uses the monthly (or weekly) difference between precipitation and PET. This represents a simple climatic water balance (Thornthwaite, 1948) which is calculated at different time scales to obtain the SPEI.

26. The SPEI is a relative measure that is it is relative to the historical drought level in that region. The SPEI number, their relationship with the severity of drought and the return period likelihood per 100 years are provided in Table 11-1. If SPEI values are positive then the climate will be wetter than normal and if negative then the climate will be drier than normal.

Table 11-1 Dry Component of the SPEI and Sample Probability of Recurrence

SPEI	Category	# of times in 100 yrs.	Severity of event
0 to -0.99	Mild dryness	33	1 in 3 yrs.
-1.00 to-1.49	Moderate dryness	10	1 in 10 yrs.
-1.5 to -1.99	Severe dryness	5	1 in 20 yrs.
< -2.0	Extreme dryness	2.5	1 in 50 yrs.

27. The projected values for drought show a probability ranging from 0% to 100% of the SPEI being less than minus 1.5. This represents a drought of either severe dryness or extreme dryness occurring.

Table 11-2 Relative drought change

Site	Scenario	Severe Dry(%)	Extreme Dry(%)
Battambang	Baseline	3.47	1.26
Battambang	2030	5.93	2.16
Battambang	2050	7.51	3.83
Kampong Cham	Baseline	2.95	2.65
Kampong Cham	2030	3.83	4.02
Kampong Cham	2050	4.73	5.38
Siem Reap	Baseline	3.80	2.24
Siem Reap	2030	4.54	2.92
Siem Reap	2050	5.06	3.44
Sihanoukville	Baseline	3.12	2.57

Sihanoukville	2030	3.74	4.29
Sihanoukville	2050	4.73	5.41

28. The values in the drought dataset represent probabilities (i.e. 0-100%). For example, a probability of 20 percent means that there is a 1 in 5 chance of an SPEI rating of<-1.5 which represents a drought of either severe dryness or extreme dryness occurring in the year of analysis e.g. 2050. The SPEI is a relative measure that represents the potential relationship of the risk of future drought to the historical drought level for that region.

29. The results already given, and for convenience repeated above in Table 11-2, show that the highest probability of a severe drought occurring is 7.5% by the year 2050 in Battambang. This equates to a 1 in 13 year event. The highest probability of an extreme drought occurring is 4.29% by the year 2030 in Siem Reap. This equates to a 1 in 23 year event.

11.4. Temperature

30. Under global warming temperature will play a more important role than precipitation in explaining drought conditions.

31. The projected results show that by the year 2050 daily peak temperatures could reach 49.5ºC. This would be a 1 in 100 year event. A more common scenario would be daily peak temperatures reaching 47ºC which would be a 1 in 10 year event.

32. There is no significant difference between inland and coastal extreme temperatures. Siem Reap shows projected temperatures about 2ºC lower than the other sites.

12. Impacts and Adaptation Measures for Each Subproject

12.1. Battambang Water Supply

12.1.1. Overview

33. The Battambang water supply requires a guaranteed raw water supply of at least 50,000m^3/day. A request has been made from MIH to MOWRAM to give a formal commitment to provide this amount but to date no such confirmation has been issued.

34. The intended off-take point is downstream of the Kanghot irrigation scheme which provides local rice farmers with irrigation water. No information was obtainable on the volumes of water supplied.

35. There is no clear agreement between national and level administration on which takes priority, water for agricultural irrigation or potable water supply for human consumption.

36. Further upstream of Kangkot Irrigation dam at a distance of 35kms is the Sek Sak Reservoir. This has a newly constructed 60 metre high rockfill dam and has a capacity of 280 million cubic metres. It contains a 13MW hydroelectric scheme.

37. At this moment it is still undergoing commissioning trials which may take 2 years to complete. MOWRAM are reluctant to give guaranteed discharge figures until the integrity of the dam and its backfilled reservoir are firmly established. Their position is that water will be

supplied if available if the needs of the hydroelectric station and the minimum ecological flow have been satisfied.

38. Downstream of the intended off-take point is the location of another water supply scheme to be funded under Korean financing. This is the Sala Ta On spillway which is 7kms downstream of Battambang. No details have yet been obtained of their off-take requirements.

Figure 12-1 Kanghot Irrigation Dam upstream of Off-take Point

39. The feasibility studies for these three schemes Kanghot, Sek Sork and Sala Ta have been requested but not yet sighted.

40. The climate change projections show that there is a 7.5% probability of a severe drought occurring by the year 2050 in Battambang. This is the highest of the four sites examined. This could be a 1 in 13 year event. This will doubtless put more strain on the agricultural activities in the area.

41. The short term rainfall increase in this location will be 12% but this is only short term intensity. The long term average rainfall may not change. There may be an increased demand for water but no concomitant increase in precipitation.

42. Until the raw water source can be guaranteed with a high degree of certainty this scheme is considered to be High Risk.

43. The climate change risk is classed as High Risk.

12.1.2. Adaptation Measures

44. **Error! Reference source not found.** below summaries the predicated impacts and adaptation measures that have been taken account of in preliminary design and project design. Of these, the development of a Water Safety Plan, ot guide management responses to potential periods of water shortages, will cost an estimated US$ 10,000 while annual costs of updating are estimated at $3,000 approximately.

Table 12-1 Summary of Impacts and Adaptation Measures for Battambang Water Supply Subproject

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Rainfall intensity effects.	Localised short-term flooding over pipelines.	System to be designed as fully pressurised with no potential for siphoning and back feeding into pipelines. Above ground pipelines, if any, to be adequately supported by well engineered support piles and foundations to prevent the undermining of the pipelines.	None – as normal designs will provide for a fully pressurised system with pipes and fittings of required specifications. Above ground supported pipelines will be designed and constructed with structurally adequate and well founded piles and foundation pads	Good design with pipes selected with adequate strength and safety factor for expected supply pressures. Structurally sound design for piles and foundation pads supporting any above ground sections of pipeline.
Maximum temperature effects	Increased per capita day consumption as a result of the higher ambient temperatures	Two percent for each ºC increase for an urban society in a developed county[17] and two liters/day[18] for a developing country (i.e. Cambodia)	None as the additional consumption is accommodated within the average per capita day consumption adopted for detailed design	Average consumption adopted for design will allow for increased average per capita day demand resulting from the higher ambient temperature within the design life of the system
Drought effects	Periods of insufficient water supply	Development of Battambang provincial waterworks Water Safety Plan (WSP) with provision for a drought response planning, awareness raising, early warning and appropriate management measures for the control of wastage and the marshalling and, if required, rationing of available supplies.	Approx $10,000 for assistance with WSP development Annual expenses of $3,000 approx for expenses relating to WSP monitoring and updating	Development, adoption and refinement of WSP during detailed design and subproject implementation phases

[17] A statistical analysis of water use in New York City showed that daily per capita water use increases by 11 litres/1°C increase in temperature (roughly 2% of current daily per capita use) (Protopapas et al., 2000)

12.2. Battambang Wastewater and Sanitation

12.2.1. Overview

45. The location for the proposed WWTP is extremely flat and already inundated with water. It is likely to be subjected to flooding and the area is designated by MPWT as having a Moderate Risk of flooding.

Figure 12-2 Site for Battambang WWTP

46. When designing the flood protection in terms of perimeter drains and platform formation, the intensity of rainfall used in the flood calculations should be increased by 12% to allow for a worst case scenario 1 in 100 year event.

47. The climate change risk is classed as Moderate Risk.

12.2.2. Adaptation Measures

48. Table 12-2 below summaries the predicated impacts and adaptation measures that have been taken account of in preliminary design and project design. Protection measures against flooding cost approximately $410,720. In addition, approx $10,000 is required for water safety plan development, and $3,000 for plan updating each year (which also applies to the water supply subproject).

[18] Health, H G Bartram J (2003). Domestic Water Quality Service Level. WHO.

Table 12-2: Summary of Impacts and Adaptation Measures for Battambang Wastewater Subproject

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Rainfall intensity effects	Risk of heightened flood causing overflowing of WWTP ponds, surcharge of network and release of raw sewage	Appropriate allowance made for increased height of bund around anaerobic ponds ($18,720), around the WWTP site $192,000) and construction of bunded sludge drying beds ($100,000). Design levels adopted to raise treatment plant and trickle filters above likely flood levels. Design of manholes and household connections to raise fittings above potential flood levels in low lying areas.	$310,720 has been allowed for bunding and site protection in the estimates of costs established by the preliminary engineering design for the WWTP site. An additional $100,000 has been allowed for site excavation and formation.	Design calculations to allow for an increase of 12% short duration rainfall intensity in overland flow paths around the WWTP without over topping of the earthen bunds around the anaerobic ponds and/or risk to the trickling filters
Maximum temperature effects	Impact on performance of the anaerobic ponds and the likelihood of algae blooms due to higher ambient water temperatures preventing water from mixing allowing algae to grow thicker and faster. Also algae blooms absorbing sunlight making water even warmer and promoting more blooms.	To consider in the detailed design process and allow provision for fitting of temporary mechanical (solar) mixers if required in the future.	None immediately	Allow for temperatures of >40^{o}C in design

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Drought effects	Reduced water used for the flushing of sewerage as a result of water restrictions or limitations could result in higher nutrient loadings of sewage feeding algal blooms and reducing plant capacity.	To consider in the detailed design process in regard to the management of the WWTP in such circumstances. Again this may require provision for fitting temporary mechanical (solar) mixers if required in the future.	None immediately but may have short-term operational implications when these circumstances arise	To be considered in the detailed design process.

12.3. Kampong Cham Water Supply

12.3.1. Overview

49. The Kampong Water supply occupies a site adjacent to the existing Water Treatment Plant. This is in an area classed as being exposed to Moderate Risk of flooding. Designs for flood protection should allow an increase of 12% on short duration rainfall intensity.

50. The climate change risk is classed as Moderate Risk.

12.3.2. Adaptation Measures

51. Table 12-3 below presents the summary of impacts and adaptation measures. Adaptation costs are $262,000 approximately.

Table 12-3: Summary of Impacts and Adaptation Measures for the Kampong Cham Water Supply Subproject

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Damage to raw water intake if Mekong River level rises and inundates the raw water intake and pumps	The intake structure and pumps are to be constructed on the edge of the river corridor above historic and anticipated flood levels	Preliminary engineering design has fully estimated the costs of the intake structure and equipment. No additional costs are anticipated, but the detailed design must reassess risk and determine the placement and level of the intake structure.	To be considered in the detailed design process.	To be considered in the detailed design process.
Damage to WTP if the area becomes inundated during flooding	The site is on formed land above likely flood plains. Notwithstanding the detailed design must assess the construction levels, and the formation of storm water overland flow paths around the WTP site to alleviate any potential risk of flooding.	Site formation and preparation assessed at $262,000, representing 5% of the cost of the WTP.	Designs for flood protection or site flooding to be based on an increase of 12% on short duration rainfall intensity	Designs for flood protection or site flooding to be based on an increase of 12% on short duration rainfall intensity
Increased per capita day consumption as a result of the higher ambient temperatures	Two percent for each °C increase for an urban society in a developed county[19] and two liters/day[20] for developing country	None as the additional consumption is accommodated within the average per capita day consumption adopted for detailed design	Average consumption adopted for design will allow for increased average per capita day demand resulting from the higher ambient temperature within the design life of the system	Average consumption adopted for design will allow for increased average per capita day demand resulting from the higher ambient temperature within the design life of the system

[19] A statistical analysis of water use in New York City showed that above 25°C, daily per capita water use increases by 11 litres/1°C (roughly 2% of current daily per capita use) (Protopapas et al., 2000)
[20] Republic of Kiribati Water supply and Sanitation Roadmap 2011 – 2030 and Kiribati Adaptation Programme.

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
The Kampong Cham water supply system will be fed from the Mekong River which has a large catchment and is also fed by the Himalaya melts and has been assessed in an earlier JICA study[21] as maintaining high flows even during predicted drought conditions.	Development of Kampong Cham provincial waterworks Water Safety Plan (WSP) with provision for a any required drought response planning, awareness raising, early warning and appropriate management measures for the control of wastage.	Approx $10,000 for assistance with WSP development Annual expenses of $3,000 approx for expenses relating to WSP monitoring and updating	Development, adoption and refinement of WSP during detailed design and subproject implementation phases	Development, adoption and refinement of WSP during detailed design and subproject implementation phases

12.4. Kampong Cham Septage Treatment

12.4.1. Overview

52. The septage treatment site is elevated and unlikely to flood. Sludge drying beds are open to the weather and may be inundated with intense rainfall. Light weight free standing roofs over the sludge beds should be considered.

53. The climate change risk is classed as Low Risk.

12.4.2. Adaptation

54. Table 12-4 presents the summarised impacts and adaptaiton measures. The estimated costs of climate change adaptation measures is $88,400.

[21] *Preparatory Survey on the Project on Additional New Water Treatment Plants for Kampong Cham and Battambang Waterworks in the Kingdom of Cambodia,* March 2013, JICA

Table 12-4: Summary of Impacts and Adaptation Measures for the Kampong Cham Septage Treatment Subproject

Climate Change effect	**Potential impacts**	**Responses in project design and preliminary engineering design**	**Cost implication**	**Recommendations for detailed design**
Rainfall intensity effects	Risk of excessive rainfall causing local flooding and the inundation of anaerobic ponds at the septage treatment facility. The risk to the sludge drying beds is minimal as the sludge clearance will be undertaken in the dry season when weather conditions are stable. Also the provision of a sludge dewatering container will minimise risks.	Appropriate allowance made for increased height of bund around anaerobic ponds ($68,400), and bunded sludge drying beds ($20,000)	$88,400 has been allowed for the bunds and site protection in the estimates of costs established by the preliminary engineering design for the septage treatment facility.	Design calculations to allow for an increase of 12% short duration rainfall intensity in overland flow paths around the septage facility without over topping of the earthen bunds around the anaerobic ponds and sludge drying beds.
Maximum temperature effects	Impact on performance of the anaerobic ponds and the likelihood of algae blooms due to higher ambient water temperatures	To consider in the detailed design process.	None immediately	Allow for temperatures of >40^{o}C in design
Drought effects	No significant potential impacts identified	-	-	-

12.5. Sihanoukville Waterwater and Sanitation

12.5.1. Overview

55. The Sihanoukville WWTP site is located close to the sea but not immediately adjacent to it. Sea level rise is not considered to be a threat.

56. The general area is considered to be at Moderate Risk from flooding and this should be taken into account when designing the pumping stations.

57. The increased temperatures may stimulate the bacterial action in the lagoons. Temperature in excess of 40^{o}C may be encountered. This should be factored into the efficiency calculations of the additional surface aerators.

58. The climate change risk is classed as Moderate Risk.

12.5.2. Adaptation

59. Table 12-5 below shows the impacts and adaptation measures identified for the subproject. Adaptation costs total an estimated $900,000 to cover supply and installation of solar powered aerators aerators to increase plant capacity and reduce reliance on mains electrical power supply.

Table 12-5: Summary of Impacts and Adaptation Measures for the Sihanoukville Wastewater Subproject

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Rainfall intensity effects	Risk of heightened flood causing overflowing of existing WWTP ponds, surcharge of pump stations and network, and release of raw sewage	Existing WWTP Lagoons are presently bunded to a level above the surrounding ground levels and to provide protection from flows in the adjacent Occheuteal Stream. However there will be the need to assess peak discharge flows in the stream and the secondary overland flow paths as part of the detailed design. The design of manholes and household connections will assess the need manholes and fittings to be raised above potential flood levels in low lying areas. A similar requirement will apply to the location of the five pump stations in the main reticulation network.	The need for any adjustment to existing bunds or secondary overland flow paths will only be know when the detailed design is carried out. Other costs associated with the design and construction of manholes and fittings, and the pump stations are already a contingent part of the costs for these items established by the pre engineering feasibility study designs	Design calculations to allow for an increase of 12% short duration rainfall intensity in overland flow paths around the WWTP without over topping of the earthen bunds around the anaerobic ponds and/or risk to the trickling filters

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Maximum temperature effects	Impact on performance of the anaerobic ponds and the likelihood of algae blooms due to higher ambient water temperatures preventing water from mixing allowing algae to grow thicker and faster. Also algae blooms absorbing sunlight making water even warmer and promoting more blooms.	The existing WWTP will be upgraded with the installation of 12 solar powered mixers/aerators to increase the capacity of the plant up to 250% to meet 2040 demands for the proposed new service areas.	The mixers/aerators with hoses, freight and installation have an estimated cost of $900,000	Allow for temperatures of >40ºC in design
Drought effects	Reduced water used for the flushing of sewerage as a result of water restrictions or limitations could result in higher nutrient loadings of sewage feeding algal blooms and reducing plant capacity.	To consider in the detailed design process in regard to the management of the WWTP in such circumstances. The proposed mixers/ aerators will assist mixing and treatment and will alleviate the risk.	Costs already provided for in the estimates established by the preliminary engineering design.	To be considered in the detailed design process.

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Land stability	ADB's "AWRENESS" filtering suggested the risk of landslides in the Sihanoukville coastal zone. Notwithstanding the geomorphology of the costal fringe of the town area would suggest that land slippage is highly unlikely.	The Sihanoukville peninsula forms an extension of the foothills of the Cardamom Mountains, which extend along the whole of the shore of the Gulf of Thailand. Landforms are gently to steeply incised. The predominant rock type is sandstone, identified[22] as the Upper Indosinian formation, of the upper Cretaceous period. This formation consists of a thick (of the order of 1000 metres) sequence of sandstone, shales, clay, marl and conglomerates.	None	None

[22] Workman, David R., Geology of Laos, Cambodia, South Vietnam and the eastern part of Thailand

Climate Change effect	Potential impacts	Responses in project design and preliminary engineering design	Cost implication	Recommendations for detailed design
Sea level rise and storm surge	Potential sea level rise and overtopping from storm surges.	The Sihanoukville WWTP site while located close to the sea it is not immediately adjacent to it. Sea level rise is not considered to be a threat. The general area is considered to be at Moderate Risk from flooding and this should be taken into account when designing the pumping stations. The coastal areas are protected by outlying islands close to the shore and the area is not subjected to long term prevailing on shore winds. Storm surge has not been an issue, and is not expected to be an issue.	Pump stations in the lower part of the catchments closer to the shore are to be located well above potential sea level rise, and at a height and distance beyond likely storm surges	To be considered in the detailed design process.

12.6. Siem Reap Interceptor Sewer Replacement

12.6.1. Overview

60. The replacement mains sewer is proposed to be 1000 mm diameter and this is the generally accepted minimum to ensure effective maintenance. The area is classed as having a Moderate Risk of flooding and this may impact on the construction program. Other than that no major climate change impacts are envisioned.

The climate change risk is classed as Low Risk.

12.6.2. Adaptation

61. Table 12-6 identifies the climate change impacts and design responses. The principal measures are primarily part of good engineering practice and the proposed adaptation is mainly requirement of high standards of construction practices, and are not incremental adaptation costs as such.

Table 12-6: Summary of Impacts and Adaptation Measures for the Siem Reap Sewer Replacement Subproject

Climate Change effect	**Potential impacts**	**Responses in project design and preliminary engineering design**	**Cost implication**	**Recommendations for detailed design**
Rainfall intensity effects	Risk associated with construction only, likelihood of occurrence of 1 in 10 year event during construction period negligible	Provision to be made in construction specification for the temporary pumping and diversion of storm water flows around construction works to approved drainage channels and without risk to adjacent properties. Also provision of temporary silt barriers to control sediment in the flows, with arrangements for the clearance and satisfactory removal of sediment.	Contractor costs to be incorporated with the contract amount.	Inclusion of elated requirements in contract documentation, and compliance by the Contractor for the design/build contract works.
Maximum temperature effects	Work conditions of employees engaged on the contract works and risk of dehydration.	Contract documents to require contractor to provide drinking water on-site for employees working in the confined site conditions for a consumption of 5 liters/ employee/ day.[23] The WHO publication *Water Requirements and Recommended Intakes*, A Grandjean 2004 provides a suitable reference document	Contractor costs to be incorporated with the contract amount.	Inclusion of elated requirements in contract documentation, and compliance by the Contractor for the design/build contract works.
Drought effects	No Identified impacts	-	-	-

[23] Dehydration is the adverse consequence of inadequate water intake. The symptoms of acute dehydration vary with the degree of water deficit (1). For example, fluid loss at 1% of body weight impairs thermoregulation and, thirst occurs at this level of dehydration. Thirst increases at 2%, with dry mouth appearing at approximately 3%. Vague discomfort and loss of appetite appear at 2%. The threshold for impaired exercise thermoregulation is 1% dehydration, and at 4% decrements of 20-30% is seen in work capacity. Difficulty concentrating, headache, and sleepiness are observed at 5%. Tingling and numbness of extremities can be seen at 6%, and collapse can occur around 7% dehydration. A 10% loss of body water through dehydration is life threatening. While the vague discomfort that accompanies a 2% dehydration may not have a significant impact, the 20 – 30% reduction in work capacity seen at 4% can have a significant negative impact on productivity. WHO 2004.

13. Conclusions

62. Climate change projections have been carried out for four sites. The projections are based on RCP8.5 for the years 2030 and 2050. Rainfall data on a daily basis for 25 years was obtained from MOWRAM.

63. Flood risks have been assessed using the MPWT in house software FRMI.

64. Projections show that the increase in intensity of rainfall during extreme weather events does not vary across the country.

65. The 1 in 10 year event by 2030 under RCP 8.5 will experience a 4 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 7% increase in 1 hour rainfall intensity.

66. The 1 in 100 year event by 2030 under RCP 8.5 will experience a 7 % increase in 1 hour rainfall intensity and by 2050 under RCP 8.5 there will be a 12% increase in 1 hour rainfall intensity.

67. The projected results show that by the year 2050 daily peak temperatures could reach 49.5^{o}C. This would be a 1 in 100 year event. A more common scenario would be daily peak temperatures reaching 47^{o}C which would be a 1 in 10 year event.

68. The highest probability of a severe drought occurring is 7.5% by the year 2050 in Battambang. This equates to a 1 in 13 year event. The highest probability of an extreme drought occurring is 4.29% by the year 2030 in Siem Reap. This equates to a 1 in 23 year event.

69. The climate change risks are given below.

City	Water Supply	Wastewater	Septage	Climate Change Risk
Battambang	X			High
Battambang		X		Moderate
Kampong Cham	X			Moderate
Kampong Cham			X	Low
Sihanoukville		X		Moderate
Siem Reap		X (sewer rehab)		Low

Table 13-1 Climate Change Risks

70. Total subproject costs and costs of adaptation are summarised below.

Subproject	Total Estimated Cost	Estimated adaptation cost	Percentage
Battambang Water Supply	$34,899,700	$72,000	0.2%
Battambang Wastewater	$10,646,687	$410,720	3.9%
Kampong Cham Water Supply	$12,765,500	$262,000	2.1%
Kampong Cham Septage	$790,000	$88,400	11.2%
Sihanoukville Wastewater	$14,653,560	$900,000	6.1%
Siem Reap Interceptor Sewer	$15,911,610	-	-
Total	**$89,667,057**	**$1,733,120**	**1.9%**

14. Annex A : GCM and RCM Data

Table A1: GCMs with 3 hourly precipitation data available

	GCM	nlat	nlon
1	ACCESS1-0	145	192
2	BCC-CSM1-1	64	128
3	BCC-CSM1-1-M	160	320
4	CCSM4	192	288
5	CMCC-CM	240	480
6	CNRM-CM5	128	256
7	EC-EARTH	160	320
8	FGOALS-g2	60	128
9	GFDL-CM3	90	144
10	GFDL-ESM2G	90	144
11	GFDL-ESM2M	90	144
12	GISS-E2-H	90	144
13	GISS-E2-R	90	144
14	HadGEM2-ES	145	192
15	inmcm4	120	180
16	IPSL-CM5A-LR	96	96
17	IPSL-CM5A-MR	143	144
18	MIROC5	128	256
19	MIROC-ESM	64	128
20	MIROC-ESM-CHEM	64	128
21	MRI-CGCM3	160	320
22	NorESM1-M	96	144

Table A2. Availability of GCM variables in the CMIP5 database

Model		Temp	Precip	SolRad	RelHum	Wind	SLR
1	ACCESS1.3	Yes	Yes	Yes	Yes	Yes	
2	ACCESS1.0	Yes	Yes	Yes	Yes	Yes	
3	BCC-CSM1-1	Yes	Yes		Yes	Yes	Yes
4	BCC-CSM1-1-m	Yes	Yes		Yes		Yes
5	BNU-ESM	Yes	Yes				
6	CanESM2	Yes	Yes	Yes	Yes	Yes	Yes
7	CCSM4	Yes	Yes	Yes	Yes		Yes
8	CESM1-BGC	Yes	Yes	Yes	Yes		

Model		Temp	Precip	SolRad	RelHum	Wind	SLR
9	CESM1-CAM5	Yes	Yes	Yes	Yes		
10	CMCC-CM	Yes	Yes	Yes		Yes	Yes
11	CMCC-CMS	Yes	Yes	Yes		Yes	Yes
12	CNRM-CM5	Yes	Yes	Yes		Yes	Yes
13	CSIRO-Mk3-6-0	Yes	Yes	Yes	Yes	Yes	Yes
14	EC-EARTH	Yes	Yes			Yes	
15	FGOALS-g2	Yes	Yes				
16	FGOALS-s2	Yes	Yes				
17	GFDL-CM3	Yes	Yes	Yes	Yes	Yes	Yes
18	GFDL-ESM2G	Yes	Yes	Yes	Yes	Yes	Yes
19	GFDL-ESM2M	Yes	Yes	Yes	Yes	Yes	Yes
20	GISS-E2-H	Yes	Yes	Yes	Yes	Yes	
21	GISS-E2-H-CC	Yes	Yes	Yes	Yes	Yes	
22	GISS-E2-R	Yes	Yes	Yes	Yes	Yes	
23	GISS-E2-R-CC	Yes	Yes	Yes	Yes	Yes	
24	HADCM3	Yes	Yes	Yes	Yes	Yes	
25	HadGEM2-AO	Yes	Yes	Yes		Yes	
26	HadGEM2-CC	Yes	Yes	Yes	Yes	Yes	Yes
27	HadGEM2-ES	Yes	Yes	Yes	Yes	Yes	Yes
28	INMCM4	Yes	Yes	Yes	Yes	Yes	Yes
29	IPSL-CM5A-LR	Yes	Yes	Yes	Yes	Yes	
30	IPSL-CM5A-MR	Yes	Yes	Yes	Yes	Yes	
31	IPSL-CM5B-LR	Yes	Yes	Yes	Yes	Yes	
32	MIROC4H	Yes	Yes	Yes	Yes		
33	MIROC5	Yes	Yes	Yes	Yes	Yes	Yes
34	MIROC-ESM	Yes	Yes	Yes	Yes	Yes	Yes
35	MIROC-ESM-CHEM	Yes	Yes	Yes	Yes	Yes	Yes
36	MPI-ESM-LR	Yes	Yes	Yes		Yes	Yes
37	ESM MPI	Yes	Yes	Yes		Yes	Yes
38	MRI-CGCM3	Yes	Yes	Yes	Yes	Yes	Yes
39	NorESM1-M	Yes	Yes			Yes	Yes

40	NorESM1-ME	Yes	Yes	Yes

Table A3: CORDEX data availability for East Asia (EAS) domain

ID	GCM RCM combination	No.
1	EAS-44-EC-EARTH-HIRRAM5	7
2	EAS-44-HADGEM2-AO-HADGEM3-RA	6
3	EAS-44-HADGEM2-AO-RegCM_v4	6
4	EAS-44-HADGEM2-AO-SNU-MM5_v3	6
5	EAS-44-HADGEM2-AO-SNU-WRF_v3	6
6	EAS-44-HADGEM2-AO-YSU-RSM_v3	6

15. Annex B References

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