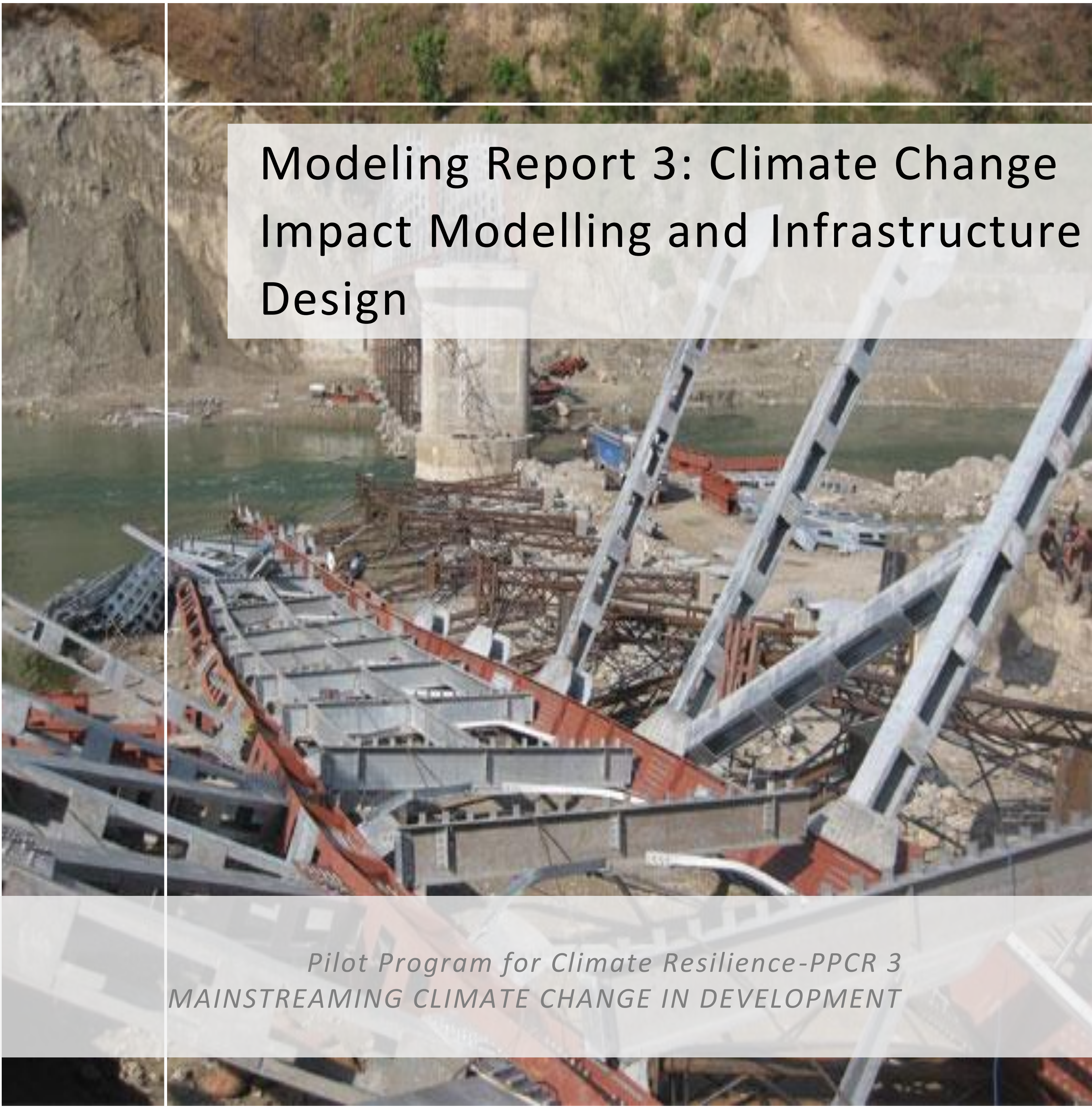
TA-7984 NEP: MAINSTREAMING CLIMATE CHANGE RISK MANAGEMENT IN DEVELOPMENT

1 Main Consultancy Package (44768-012)

Modeling Report 3: Climate Change Impact Modelling and Infrastructure Design



Pilot Program for Climate Resilience-PPCR 3

MAINSTREAMING CLIMATE CHANGE IN DEVELOPMENT

Mainstreaming climate change risk management in development modelling reports set

This report forms part of a set on the modelling results of the TA7984-NEP Mainstreaming climate change risk management in development project, The full set includes:

1. **Modelling report 1:** Draft climate change threat profiles for eight case study districts
2. **Modelling report 2:** Final climate change threat profiles for eight case study districts
3. **Modelling report 3:** Climate change impact modelling and infrastructure design
4. **Final modelling report:** Modelling manual

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DEFINITIONS

Bridge: A structure that allows people or vehicles to cross an obstacle such as a river or canal. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it.

Culvert: A culvert is any kind of channel or tunnel that directs unwanted water away from roads and other corridors of travel. It is typically built underground to prevent inconveniently located streams and runoff from flooding roads, highways and streets.

Drainage: The natural or artificial removal of surface and sub-surface water from an area.

Dike: An elongated naturally occurring ridge or artificially constructed fill or wall, which regulates water levels. It is usually earthen and often parallel to the course of a river in its floodplain.

Gabions: Rectangular wire mesh baskets filled with rock to form flexible, permeable, monolithic structures such as retaining walls. When gabions are filled with stone they become large, flexible building blocks from which a broad range of structures can be built. Gabions are often used for erosion control, bank stabilization, channel linings, and weirs.

Highway: Any public road or other public way on land. The term is used for major roads, but also includes other public roads and public tracks.

House: A house is a building that functions as a home for humans or other creatures. They can range from huts to complex structures. The social unit that lives in a house is known as a household. Most commonly, a household is a family unit of some kind, although households may also be other social groups or individuals.

Intake structure/ pumping station: Directs water from the source of supply, such as a reservoir or a river, into the community.

Irrigation channel: A waterway, often man-made or enhanced, built for the purpose of carrying water from a source such as a lake, river, or stream, to soil used for farming or landscaping.

Physical infrastructure: The basic physical structures required for an economy to function and survive, such as transportation networks, water supply network, a power grid, buildings, drainage systems and sewerage and waste disposal systems.

Return period: The return period for a hydrological event of specified magnitude at a given location is the average length of time between occurrences of that hydrological event at the specified magnitude or greater.

Revetment: Sloping structures placed on banks or cliffs in such a way as to absorb the energy of incoming water.

River training: River training solutions are being widely used by civil engineers to change the beds and banks of rivers in order to meet some human purpose such as controlling floods, preventing erosion, enhancing water supply or forming shipping channels. It aims to prevent future damage and safeguard essential public works like water pipes, sewage plants, reservoirs and roads.

River training structures: River training structures are manmade structures designed and constructed in a river reach to modify the hydraulic flow and sediment response of a river. Some examples of manmade river training structures are dikes, chevrons, bend way weirs, and bank revetments. Gabions and reno mattresses are commonly used in river training structures such as sills, groynes, energy dissipation basins, sills and weirs.

Road: A thoroughfare, route, or way on land between two places, which has been paved or otherwise improved to allow travel by some conveyance including cars, buses and trucks.

Sand mining: A practice that is used to extract sand, mainly through an open pit. However, sand is also mined from river bedhttp://en.wikipedia.org/wiki/Beach and hill dunes.

Storage reservoir: A dam placed in a watercourse to increase the depth of water or to divert it into a pipes to provide a water source.

Water supply system: A facility that provides a source of water. Generally it is an arrangement of reservoirs, purification plant, distribution pipes, etc, for providing water to a com munity.

1 CONTEXT

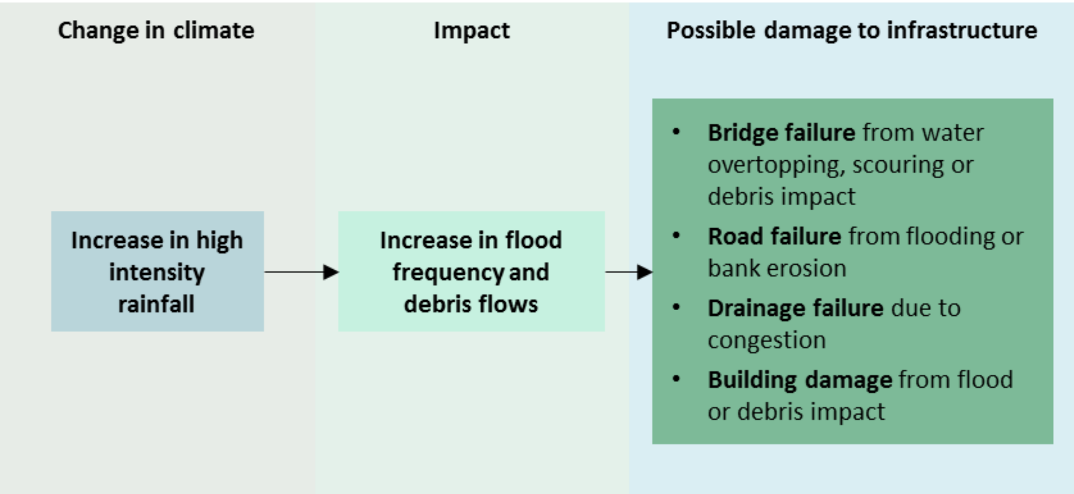
1.1 BACKGROUND

Nepal needs a comprehensive set of infrastructure to continue on its path of development. A country's physical infrastructure consists of a broad array of systems and facilities that house and transport people and goods, and provides services. Basic physical infrastructure systems include roads, bridges, canals, water supply, buildings and urban areas, protection from water induced disasters and sewage treatment. These systems are considered essential for enabling productivity in an economy and are the backbone of the socio-economic development of any country.

In Nepal, infrastructure systems are generally designed to withstand historical local weather and climate. Design engineers typically refer to historical records of climate, especially extreme weather events, when designing infrastructure. For example, bridges are often designed to withstand storms that have a probability of occurring only once or twice every 100 years. However, due to climate change, the historical climate is no longer a reliable predictor of the future.

Climate change is projected to increase the frequency and intensity of extreme weather events in Nepal. Specifically, landslides will become more severe, extreme rainfall will amplify floods, and storms will become more intense. These changes could increase the risk of delays, disruptions, damage, and failure in the Nepal's infrastructure systems. Figure 1-1 provides an example of the potential infrastructure damage that could be caused by changes in rainfall intensity.

Figure 1-1 Potential climate impact on Infrastructure from increasing rainfall intensity



Key elements of rural and urban systems, including transportation, communication, drainage, and energy are vulnerable to climate change and extreme weather, and most infrastructure being built now is expected to last for 50 years or longer. Therefore, it is important to understand how future climate might affect these investments in the coming decades, and Nepal infrastructure design and risk-management approaches need to be re-examined and revised to reduce the potential impacts.

1.2 GOVERMENT SECTORS FOR INFRASTRUCTURE DEVELOPMENT IN NEPAL

In Nepal, seven key government sectors have been prioritised for assistance in building resilience to climate change. These sectors are the focus of this report.

Department of Roads (DoR): Established along with Department of Buildings after splitting from the Public Works Department (PWD) in 1970. The departmental goal is that "the Roads Department is able to provide the People of Nepal with a safe, cost effective and well maintained road network". DoR has the capacity to plan, manage and deliver its full range of responsibilities in respect to the main road and bridge networks and to be accountable for these duties.

Department of Local Infrastructure Development and Agriculture Road (DoLIDAR): DoLIDAR is a technical wing of the Ministry of Federal Affairs and Local Development. The objective of DoLIDAR is to undertake infrastructure development programmes in rural areas. It is responsible for assisting local district governments in the engineering aspects of civil engineering construction. It has branch offices in all 75 districts. Its main job is to undertake or arrange to undertake planning of a range of local-level infrastructure including rural roads, irrigation and river control works, water supply and sanitation, suspension bridges, housing and buildings, and rural energy provision in co-ordination with local authorities.

Department of Water Induced Disaster and Prevention (DWIDP): The Water Induced Disaster Prevention Technical Centre (DPTC) was established under the Ministry of Water Resources under an agreement between the Government of Nepal and the Government of Japan on 7 October 1991. To institutionalize the objectives and achievements of the DPTC, the Department of Water Induced Disaster Prevention (DWIDP) was established on 7 February 2000 under the Ministry of Water Resources. The department is now under the Ministry of Irrigation. The main activities of the department are i) technology development and training; ii) study and information; and iii) water-induced disaster mitigation. Under the water-induced disaster mitigation work the department carries out emergency works, point control works and long-term mitigation works through the preparation of master plans.

Department of Urban Development & Building Construction (DUDBC): Established along with Department of Roads after splitting from the Public Works Department (PWD) in 1970 A.D. The main role and responsibility of the Department is construction of safe, economical and environmentally friendly buildings, affordable housing and other works to enable sustainable urban development.

Department of Water Supply and Sewerage (DWSS): The Department of Water Supply and Sewerage (DWSS), established in 1972, is the lead agency for the drinking water supply and sanitation sector of Nepal. The main objectives of DWSS are to: i) provide and ensure safe, convenient and adequate water supply to all Nepalese, with sanitation as an integral component, and with specific focus on disadvantaged groups; ii) reduce the incidence of water-related diseases prevalent in the country; and iii) reduce suffering and drudgery of women and children, traditionally responsible for collecting water and domestic sanitation and hygiene. DWSS is currently implementing various programs both in the urban and the rural areas to achieve these objectives and to meet the national target of universal access to water and sanitation services by 1960.

Department of Irrigation (DoI): Construction of modern irrigation system started in Nepal in 1922 during Rana regime with Chandra Nahar, the Department of Canal was formally established in 1952 under the ministry of Construction and Communication. The department then passed different stages working under different ministries and finally ended up as Department of Irrigation in 1987. Since the establishment of Ministry of Irrigation (MoI) in 2009, DoI has been working under it.

Department of Irrigation (DoI): Has a mandate to plan, develop, maintain, operate, manage and monitor different modes of environmentally sustainable and socially acceptable irrigation and drainage systems - from small to larger scale surface systems and from individual to community groundwater schemes. Its ultimate aim is to provide year round irrigation facilities and increase the irrigable area of the country. DoI also has to carry out river training activities to protect flood ways, floodplains and agricultural lands in the form of river bank protection.

1.3 CLIMATE RELATED INFRASTRUCTURE DESIGN STANDARDS IN NEPAL

The Government of Nepal infrastructure development departments use various well-established formulas for calculating design parameters such as highest flood level, flood frequency, crop demands, expansion of bridge materials, crop production and sizes of infrastructure such as rain water harvesting tanks. For example, at least five formulas are used for estimating hydrological and hydraulic parameters when designing infrastructure near a river (Table 1-1 and Table 1-2). These formula's generally make use of statistical analysis of historical observations or empirical or conceptual models of the relevant watershed and meteorology. For example, in the design of facilities such as storm drain systems, culverts, and bridges, the consideration of floods normally uses peak runoff or discharge in cubic meters per second, which is calculated in one of three ways: i) the Rational formula is generally used for discharge estimation from precipitation; ii) the Mannings equation method is useful if the extreme event flood is known; and iii) flood frequency analysis is generally carried out if gauged data is available from hydrometeorology stations. To incorporate climate change considerations into infrastructure design, the projected time series (i.e. time series that incorporate the effects of climate change) need to be incorporated into the use of design formulas in Nepal.

Table 1-1 Methods use for hydrological parameter estimation for infrastructure design in Nepal

Hydrological parameter	Formulas	Infrastructure
Highest Flood Level	Manning's equation Rating curve	Road, buildings, bridge, culvert, barrage
Estimation of flood from precipitation	Rational Formula	Drainage, small catchment runoff, storage tank design, design discharge for bridge, culvert, barrage, canal design
Flood frequency analysis	Statistical analysis of observed historical discharges	Road, bridge, culvert, barrage, canal design
Scour depth	Lacey's theory	Canal, bridge, culvert, barrage
Water way width	Lacey's theory	Canal, bridge, culvert, barrage

Table 1-2. Design Return Periods used by DoLIDAR (Source: DoLIDAR)

S.N	Structure	Design return period in years
1	Irrigation supply reliability	5 (i.e. failure of supply once every five years)
2	Road culverts	5 to 10 years depending upon the type of crossings
3	Highway bridge	10 to 50 years depending upon the type of river
4	Irrigation intake	10 to 25 years
5	Irrigation weir/barrage	50 to 100 depending upon its size
6	Cross drainage structures	10 to 25 years

1.4 REPORT OBJECTIVES

This report outlines the findings of modelling activities undertaken under the project TA 7984-NEP Mainstreaming Climate Change Risk Management in Development (MCCRMD). More specifically this reports aims to provide the following information for use by the infrastructure departments of the Government of Nepal:

- Projected changes in design flood, rainfall intensity duration, rainfall frequency and temperature changes generalised for six areas of Nepal (Chapter 3);
- Example applications of climate change projection results in formula's used for infrastructure design used in Nepal (Chapter 4); and
- Possible uses of the climate change projection results for development sectors in Nepal (Chapter 5).

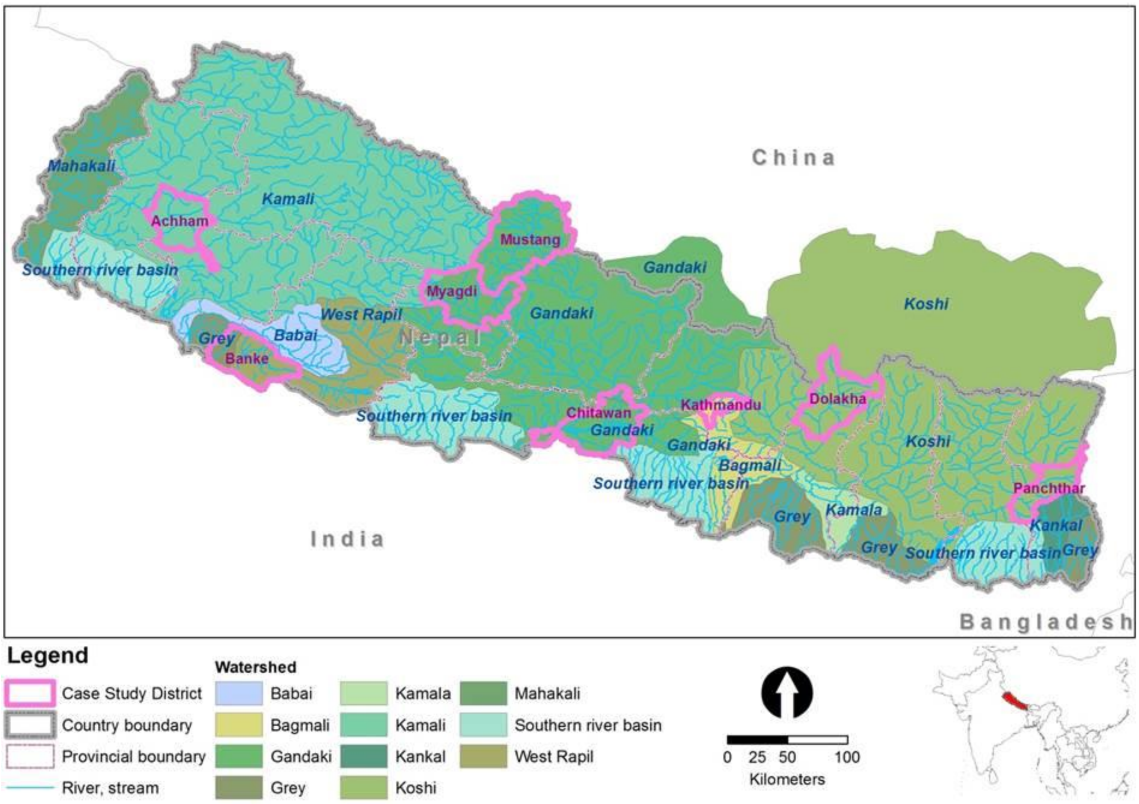
2 HYDROLOGICAL MODELLING OF CLIMATE CHANGE IMPACTS

The purpose of modelling undertaken under MCCRMD is to use existing climate change projections to understand the possible impacts of climate change on hydrological systems in Nepal. For this purpose a hydrological model is used to convert historical and projected atmospheric variables (rainfall and temperature) to flow and other important parameters (Figure 2-1). Then statistical analysis techniques are used to analyse the changes in climate and the possible impacts on infrastructure systems.

Figure 2-1 Overall process for CC impact study

Modelling was undertaken for a total of eight districts (Figure 2-2). The districts were chosen to represent the diversity of ecology, infrastructure development, climate and climate change vulnerability across Nepal. The broad conclusions drawn in this report are based on the results for these eight districts only. They provide a generalised projection of the likely climate change impacts across Nepal but should not be used for detailed planning. Only data specifically prepared for a district should be used for the purpose of detailed infrastructure planning and design.

Figure 2-2 Districts for which climate change impacts have been modelled



2.1 INPUT DATA COLLECTION AND PROCESSING

a. Baseline hydro-meteorological data

Historical observation data for each district was obtained from the Department of Hydrology and Meteorology. Time series were collected from a total of 49 stations spread across the eight districts. The data was prepared in three steps:

(i) **Compilation and formatting**: Combining the separate parameter, year and station files into continuous time series that can be used in modelling. For example in Kathmandu district 1,300 separate rainfall files were combined into continuous station files.
(ii) **Gap filling:** Modelling requires continuous time series whereas historical monitoring time series often contain gaps. Gaps are filled by correlating the time series to a nearby station and then using the correlation function to fill in missing data.
(iii) **Quality control**: Quality control has two main tasks: checking for 0-values that should be converted to missing values; and checking for unrealistic (too large or too small) values.

The baseline period was set as 1980 to 2000.

b. Future climate projections

The modelling used downscaled climate change projection datasets previously prepared under ADB TA 7173 Strengthening Capacity for Managing Climate Change and the Environment. The datasets were obtained from Nepal Department of Hydrology and Meteorology and the Asian Disaster Preparedness Centre. The projection datasets are based on three global General Circulation Models (GCMs):

- PRECIS – Providing Regional Climate scenarios for Impact Studies – is based on HadRM3 developed at the Hadley Centre and UK Met Office;
- RegCM4 -- Regional Climate Model version 4 – is developed at the International Centre for Theoretical Physics, Italy and Physics of Weather Climate Centre at National Centre for Atmospheric Research (NCAR), USA; and
- ARPEGE has been developed for operational numerical weather forecast by Météo-France in collaboration with ECMWF (Reading, U.K.) it applies the WRF- Weather Research and Forecasting model version 3.2 developed by NCAR for high resolution downscaling.

The TA modelling team identified a number of issues with the downscaled datasets and developed an approach to create improved climate projection datasets (see Technical Note, Review of historical and future projection meteorological data for TA 7984 CC threat assessments, February 2012, for more detail on the issues identified). The approach for improving the datasets has four main steps:

1. **Development of high quality historical observed dataset**: The historical observed dataset is improved by i) combining fragmented yearly historical datasets into continuous time series; ii) iteratively gap filling data gaps using nearby stations; and iii) quality control and correction of possible data errors.

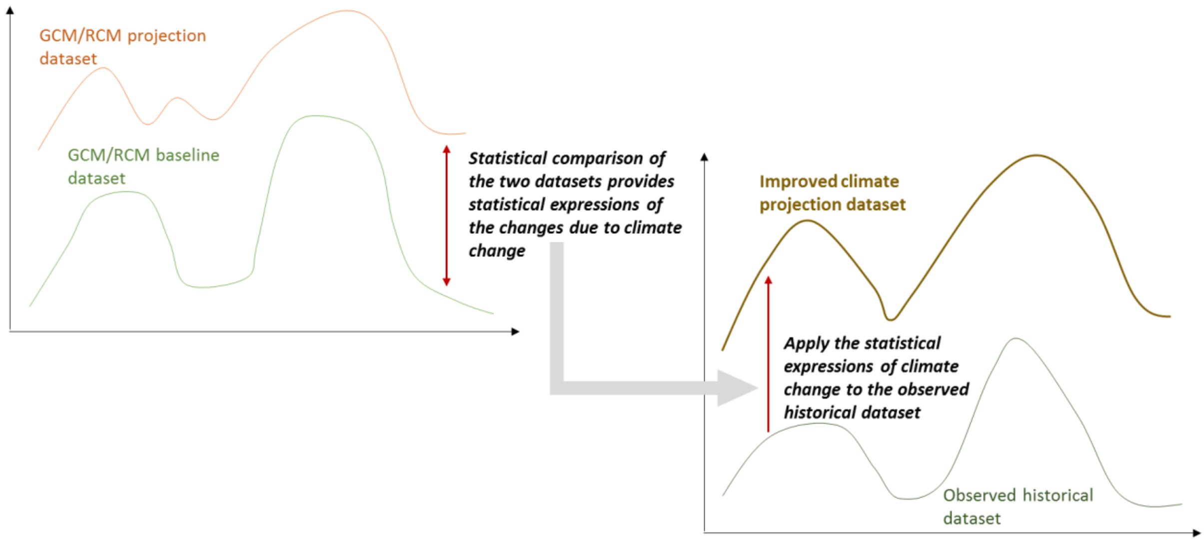
2. **Extraction of GCM/RCM datasets and interpolation to observations stations**: The GCM/RCM data is extracted and interpolated to provide downscaled baseline and projection datasets for stations where observed data has been collected by i) extracting baseline and projection time series from GCM/RCM gridded NetCDF data files; and ii) interpolating GCM and RCM baseline and projection time series to station locations including height correction (i.e. rainfall increases and temperature decreases as a function of elevation).

3. **Statistical comparison of modelled baseline and projected future datasets**: The modelled baseline and projection datasets are statistically analysed to calculate statistical

expressions of the changes due to climate change including calculation of monthly average, variability, extremes and change in number of dry days for each station; and

4. **Development of high quality climate projections dataset**: The statistical expressions of climate change are applied to the historical observed dataset to calculate an improved climate change projection dataset (Figure 2-3) and the results interpolated to the hydrological model grid using height corrections.

Figure 2-3 Utilising modelled historical and projection datasets to develop improved climate projections



The approach to create improved climate (projection) datasets for temperature and precipitation for each district was applied using the results of one GCM - PRECIS. The PRECIS downscaling is considered to be most reliable in representing baseline climate. The projected datasets were developed for the time period of 2040 to 2060, centred around 2050.

2.2 THE IWRM HYDROLOGICAL MODEL

The quality controlled historical data and improved climate change projection data for temperature and precipitation were incorporated into a distributed basin-wide hydrological model titled VMOD/IWRM. In distributed modelling the watershed is divided into small grid cells (Figure 2-4). The model grid is constructed by combining soil, land use, topography and the river network together with meteorological data, water utilisation and infrastructure (Figure 2-5). Hydrological and other processes are computed in each grid cell and the grid cells are connected through mass transport above soil (rivers and overland flow) and in the soil, thus allowing calculation of hydro-meteorological parameters throughout the basin of focus.

Figure 2-4 Schematic representation of the IWRM model

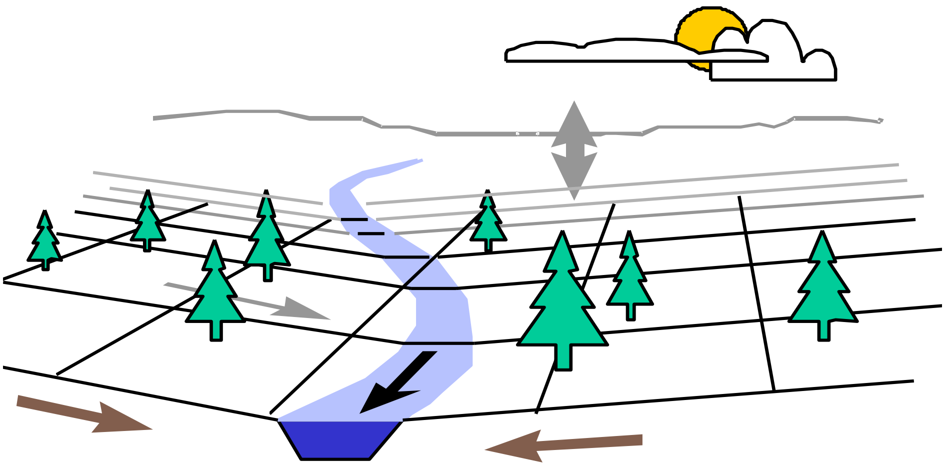
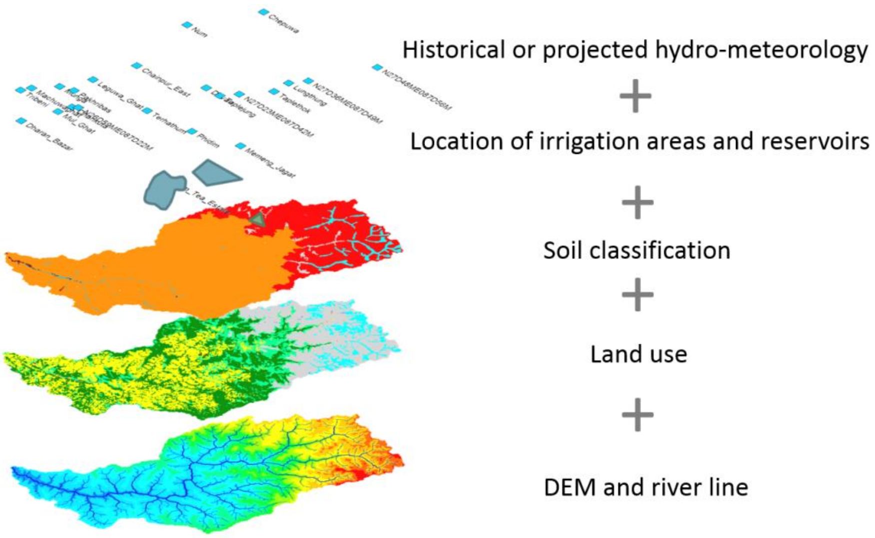


Figure 2-5 IWRM model construction.



The model is calibrated to measured discharge values. Some model parameters are well established from literature or from previous applications and therefore remain more or less constant between different model applications. Other parameters are related to individual watershed parameters and need to be calibrated – this typically includes soil properties, especially soil thickness and water conductivity. The coefficient of determination based on the square of difference between the modelled and measured value (R^2) is used for determining goodness of model fit. When R^2 is 1 the fit is perfect. If modellers have access to good meteorological data coverage of a model area the discharge R^2 can be quite high, between 0.9 and 0.98. In other cases, where data availability is not as good, R^2 values can be much lower.

For the eight Nepal district models, despite limitations in data coverage and quality and the time available for model calibration, the models represent the hydrological characteristics quite well. Application of the model in eight districts of Nepal reached R^2 values ranging from 0.3 – 0.8. Therefore, by incorporating climate change projections into the models, the modelling results can provide reliable estimates of the projected changes in hydro-meteorology for each district.

The main factors affecting the accurateness of hydrological modelling results are:

- Lack of data for the highest rainfall areas on the mountain slopes and other difficult to access locations;
- Limited information on snowfall and snow depth;
- High mountain humidity condensation affects are not included in the model; and
- Discharge measurements used for calibration are based on rating curves which relate water levels to flow, in many cases these rating curves are out of date and provide inaccurate estimates of flow.

A much larger issue than the hydrological modelling accuracy is confidence in climate change projections. Temperature projections are considered rather reliable and the projections can be also verified to some extent by historical data. However, precipitation projections contain large uncertainties especially for monsoon areas[1]. Due to these uncertainties the TA has taken the following approach:

- Focus on current climate, its variability and extremes – this provides wealth of information about climate vulnerability and adaptation measures; and
- Development of improved dataset by adding statistical representations of projected changes to the baseline (Figure 2-3)– this reduces the possible biases and errors in the climate models.

2.3 STATISTICAL ANALYSIS OF MODELLING RESULTS

The Mathwave Easyfit-Data Analysis and Simulation software was used to undertake statistical analysis of the hydrological modelling results. The software was used to:

1. **Fit distributions:** Fitting distributions involves the use of statistical methods to estimate distribution parameters based on sample data. The EASY FIT software implements parameter estimation methods for most commonly used distributions and automatic distribution fitting allows for fitting a large number of distributions.
2. **Select the best fitting distribution:** After distributions are fitted, we compare them and select the best fitting model. Goodness of fit tests can be used to determine whether a certain distribution is a good fit. Calculating the goodness of fit statistics also enables *ordering of the fitted distributions* according to how good they fit the dataset.
3. **Apply the selected distribution**: The selected distribution is then used to model the process of focus – i.e. flood recurrence or rainfall intensity recurrence.

[1] *Climate change 2013: The physical science basis*. Working group I contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

3 REGIONALIZED CLIMATE CHANGE IMPACT MODELLING RESULTS

Detailed modelling results for eight case study districts have been provided in MCCRMD Modelling Reports 1 and 2. Here we present regionalised results for six areas of Nepal. The modelling results are separated area wise as Far Western Hilly (FW-H), Western Hilly (W-H), Central Hilly (C-H), Eastern Hilly (E-H), Western and Far Western Low Land (W&FW-L) and Central and Eastern Low Land (C&E-L) (Figure 3-1). The modelling results from eight pilot districts were used to generate generalised results for each area (Table 3-1).

It must be noted that these results are based on a total of eight districts across Nepal, ranging from 1 to 2 districts modelled for each area (Table 3-1). Therefore the broad conclusions drawn in this chapter provide a generalised projection of the likely climate change impacts across different areas of Nepal but should not be used for detailed planning. Further modelling is being planned by DHM so that all districts across Nepal will be covered by climate change impact modelling.

Figure 3-1 Areas for which generalised results are reported

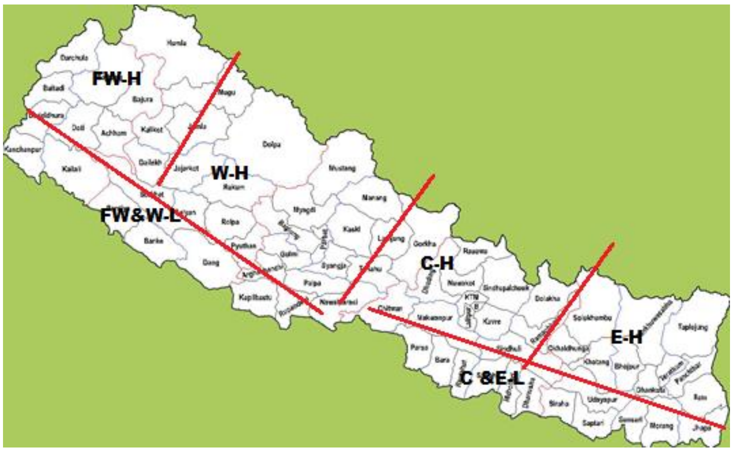


Table 3-1. Districts in each area where climate change threats were modelled

Area	Districts where modelling was undertaken
Far Western Hilly (FW-H)	Aacham
Western Hilly (W-H)	Mustang and Myagdi
Central Hilly (C-H)	Dolkha and Kathmandu
Eastern Hilly (E-H)	Panchtar
Far Western and Western Low Land (FW&W-L)	Banke
Central and Eastern Low Land (C&E-L)	Chitwan

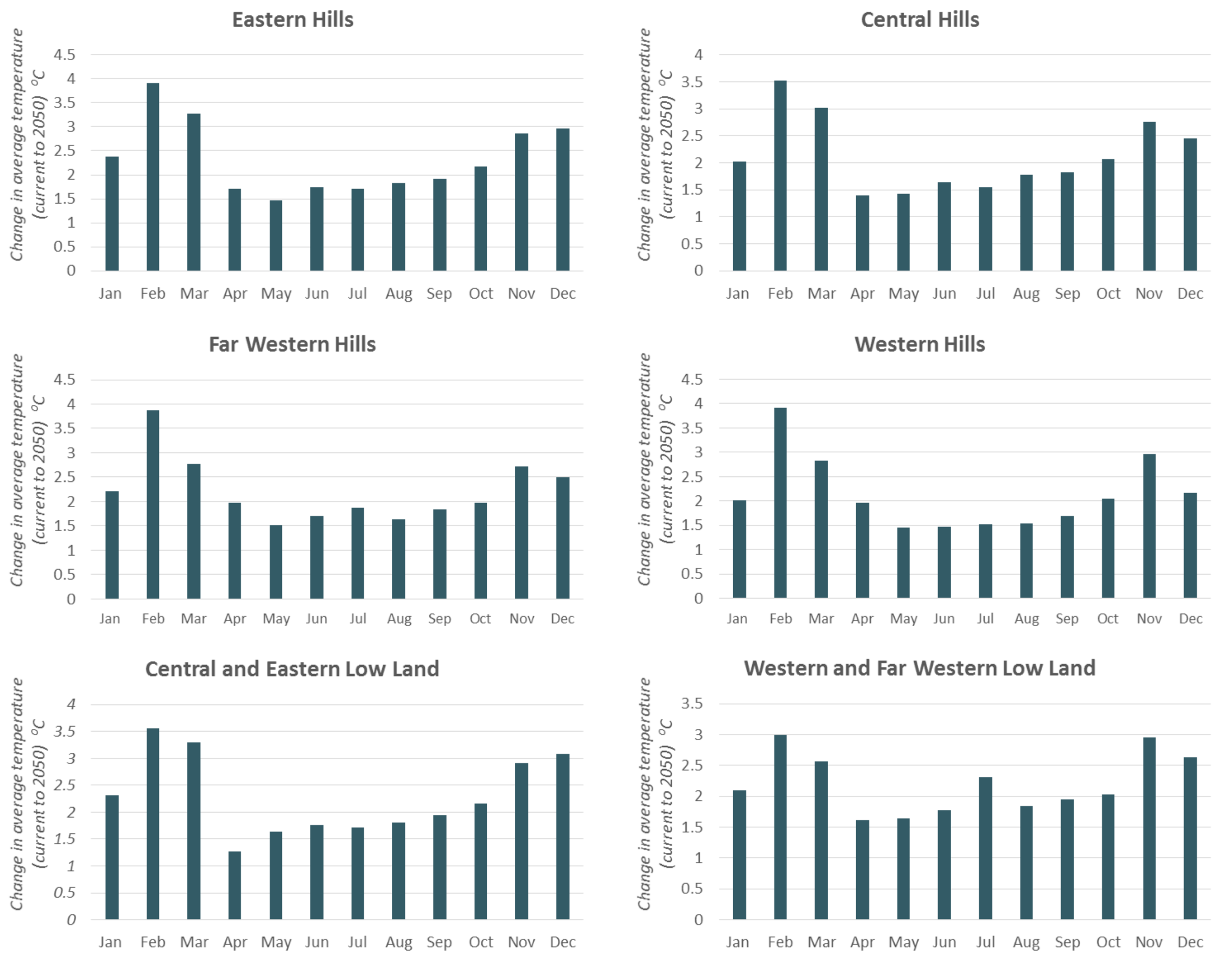
3.1 TEMPERATURE

The generalized monthly and annual change in average temperature for each area is depicted in Table 3-2 and Figure 3-2. The monthly temperature increase is expected to range from 1.3 Deg C to 3.9 Deg C across Nepal. The highest changes in temperature are projected to occur in February, reaching up to a 3.9 Deg C increase in the Eastern Hills. The lowest increases are projected to occur in the Central and Eastern Low Lands in April, only a 1.3 Deg C increase.

Table 3-2 Projected change in monthly average temperature between 2000 and 2050

Month	FW-H	W-H	C-H	E-H	W&FW- L	C &E -L
Jan	+2.2	+2.0	+2.0	+2.4	+2.1	+2.3
Feb	+3.9	+3.9	+3.5	+3.9	+3.0	+3.6
Mar	+2.8	+2.8	+3.0	+3.3	+2.6	+3.3
Apr	+2.0	+2.0	+1.4	+1.7	+1.6	+1.3
May	+1.5	+1.5	+1.4	+1.5	+1.6	+1.6
Jun	+1.7	+1.5	+1.6	+1.7	+1.8	+1.8
Jul	+1.9	+1.5	+1.5	+1.7	+2.3	+1.7
Aug	+1.6	+1.5	+1.8	+1.8	+1.8	+1.8
Sep	+1.8	+1.7	+1.8	+1.9	+2.0	+1.9
Oct	+2.0	+2.1	+2.1	+2.2	+2.0	+2.2
Nov	+2.7	+3.0	+2.8	+2.9	+2.9	+2.9
Dec	+2.5	+2.2	+2.4	+3.0	+2.6	+3.1
Annual	**+2.2**	**+2.1**	**+2.1**	**+2.3**	**+2.2**	**+2.3**

Figure 3-2 Generalised projected changes in temperature for each area



3.2 PRECIPITATION

Projected changes in average annual/seasonal rainfall volumes, one day rainfall event frequencies and average rainfall intensities are outlined in Table 3-3 to

Table 3-5. From these results the following preliminary conclusions can be drawn:

- **Annual rainfall volumes will increase across Nepal** with the highest increase in the Western Hills and the lowest increases in the Central and Eastern Lowlands;
- **Monsoon rainfall volumes will increase in most areas of the country** reaching up to 20% increase in the Eastern Hills, **only in the Far Western Hills will monsoon rainfall decrease** (by 8.7%);
- **Winter rainfall volumes will decrease across Nepal**, with the largest decrease occurring in the Far Western and Western Lowlands, and the smallest decrease occurring in the Eastern Hills;
- Across Nepal **rainfall events which have historically occurred every 100 years will now occur more often**, including almost twice as often in the Eastern Hills; and
- **Rainfall intensities will increase across Nepal**, most notably in the Central and Eastern Hills.

Table 3-3 Projected changes in annual and seasonal precipitation in Nepal (from 2000 to 2050)

Region	Percentage change in annual rainfall	Percentage change in monsoon rainfall	Percentage change in winter rainfall	Percentage change in premonsoon rainfall	Percentage change in postmonsoon rainfall
FW-H	+ 2.6	-8.7	-27	+28	+ 144
W-H	+23	+4.4	-46	+47	+23
C-H	+9.5	+13	-78	+27	+1
E-H	+22	+20	-18	+70	+79
C&E-L	+1.9	+2.4	-57	+24	-41
FW&W-L	+9.5	+13	-78	+27	-1

Table 3-4 Projected changes in frequency of 100 yr, 50 yr and 25 yr ARI one day rainfall events in areas of Nepal (from 2000 to 2050)

Region	Change in frequency of historical 100 yr ARI one day rainfall event	Percentage change in frequency of historical 50 yr ARI one day rainfall event	Percentage change in frequency of historical 25 yr ARI one day rainfall event
FW-H	+ 20%	+ 19%	+17%
W-H	+25%	+19%	+17%
C-H	+40%	+36%	+30%
E-H	+46%	+ 38%	+25%
C&E-L	+17%	+15.8%	+15%
FW&W-L	+15%	+11%	+10%

Table 3-5 Projected changes in average rainfall intensity (average of 10 to 60 minute duration events) for 100 yr, 50 yr and 25 yr ARI events in areas of Nepal (from 2000 to 2050)

Region	Change in rainfall intensity (Average 10 -60min) for 100 yr ARI event	Change in rainfall intensity (Average 10 -60min) for 50 ARI yr event	Change in rainfall intensity (Average 10 -60min) for 25 yr ARI event
FW-H	23%	18%	12%
W-H	22%	20%	17%
C-H	35%	30%	27%
E-H	50%	40%	32%
C&E-L	14%	13%	12%
FW&W-L	14%	11%	9%

3.3 FLOWS AND FLOODS

Projected changes in annual and seasonal flows, dependable flows, design flows and suspended sediments sediments for each area are outlined in Table 3-6 to

Table 3-9. From these results the following preliminary conclusion can be drawn:

- **Mean annual flow will generally increase** in rivers across Nepal, except for the Central & Eastern Lowlands where annuals flows may decrease slightly**;**
- **Winter flow will decrease except in the Eastern Hills and the Far West Hills**;
- **The direction of change in monsoonal flows will vary across the country**, with increases in the Western Hills, Central Hills, Eastern Hills and Far Western & Western Lowlands, and decreases in Far Western Highlands and Central & Eastern Lowlands;
- The **highest increases on monsoon flow will be in the Eastern Highlands** – reaching up to a 33% increase;
- **Dependable flows are generally expected to increase across Nepal**, a good sign for agricultural productivity. The 80% dependable flow is projected to decrease in only two areas– the Central Hills and Central and Eastern Low Lands;
- **2, 25, 50 and 100 year Annual Recurrence Interval flood volumes are expected to increase** by between 6 to 48% ;
- **The largest flood volume increases are projected to occur in the Far Western and Eastern Hills**, and the lowest in the Far Western and Western Low Lands;
- **Total suspended sediments are projected to increase across the country,** including by almost a quarter in the Far Western Hills; and
- **Increases in the average total suspended sediments will be highest in the Far Western Hills** and lowest in the Far Western & Western Low Lands.

Table 3-6 Projected changes in annual and seasonal flows in areas of Nepal

Region	Percentage change in mean annual flow	Percentage change in mean monsoon flow	Percentage change in mean Winter flow	Percentage change in mean pre-monsoon flow	Percentage change in mean post-monsoon flow
FW-H	+9	-12	+2	+35	+42
W-H	+23	+4.4	-46	+47	+23
C-H	+16	+19	-22	+26	+1
E-H	+ 39.8	+ 33	+9	+28	+ 55
C&E-L	-4.3	-5.6	-28	+30	-8.3
FW&W-L	+9	+4	-8.4	+56	+9

Table 3-7 Projected changes in dependable flows in areas of Nepal

Region	Change in 80 percent dependable flow	Change in 40 percent dependable flow	Change in 10 percent dependable flow
FW-H	+19%	+24%	+30%
W-H	+14%	+40%	+30%
C-H	-9%	+4%	+16%
E-H	+20%	+78%	+30%
C&E-L	-2.5%	+15%	+7.6
FW&W-L	+10%	+4%	+2%

Table 3-8 Projected changes in design flood in areas of Nepal

Region	Percentage change in 2 yr ARI flood discharge	Percentage change in 25 yr ARI flood discharge	Percentage change in 50 yr ARI flood discharge	Percentage change in 100 yr ARI flood discharge
FW-H	+35	+42	+45	+48
W-H	+17	+21	+22	+24
C-H	+26	+30	+33	+35
E-H	+36	+38	+39	+40
C&E-L	+5.5	+13	+26	+27
FW&W-L	+10	+15	+16	+17

Table 3-9 Projected changes in sediment flow in areas of Nepal

Region	Percentage change in total suspended sediments
FW-H	+23.5
W-H	+18.5
C-H	+17.6
E-H	+14
C&E-L	+13.5
FW&W-L	+9.5

4 EXAMPLE APPLICATIONS OF MODELLING RESULTS IN INFRASTRUCTURE DESIGN

The modelling results developed in MCCRMD will be useful to the development sector departments for ensuring that their planning and design is made climate change inclusive. The following chapter outlines some example applications of how climate change projections can be incorporated into infrastructure design formulas.

4.1 EXAMPLE APPLICATIONS OF INCREASE IN TEMPERATURE

a. Example 1 – Temperature induced longitudinal displacements

Overview

Changes in temperature causes structures to expand and contract. These movements should be taken into account in the design of displacement tolerances for structures. This is relevant for design of all types of structures, especially where different materials meet each other, or when long structures are built (e.g. bridges).

Theoretical details

The effective temperature is a theoretical temperature derived by weighting and adding temperatures at various levels within a bridge superstructure. Daily and seasonal fluctuations in air temperature, solar radiation and re-radiation cause changes in the effective temperature of the superstructure which, in turn governs its movement. Over a period of time there will be a minimum, a maximum, and a range of effective bridge temperature, resulting in loads and/or load effects within the superstructure. Daily and seasonal fluctuations in shade air temperature and solar radiation also cause changes in the temperature of other structural elements such as piers, towers and cables.

In Nepal, the DOR uses the AASHTO Standard Bridge Specifications (1996) recommended equation for estimating temperature-induced longitudinal displacements if no restrictions were imposed at the ends of the bridge deck (Equation 1).

$$\Delta_{Lb} = (\alpha \Delta_T) L_b (\textbf{Equation 1})$$

Where,

Δ_{Lb} = bridge displacement (expansion or contraction), same units as L_b

α = coefficient of thermal expansion, 0.0000065 / °F and 0.000006 / °F for steel and concrete bridges, respectively (AASHTO Standard Bridge Specifications, 1996)

Δ_T = temperature difference between the effective bridge temperature and the effective temperature at time of construction

L_b = length of bridge from the neutral point (usually the centre of the bridge) to abutment.

Incorporating climate change

As the air temperature increases with climate change, ΔT will increase leading to additional displacement of the bridge. Table 3-2 and Figure 3-2 could be used to provide likely increases in temperature and therefore, using Equation 1, provide an estimate of the change in expansion that can be expected from bridges and other steel structures.

b. Example 2 – Crop water demand

Overview and theoretical details

To design an irrigation canal, it is necessary to estimate the crop water requirements of the command area. In Nepal, DOI calculate crop water demands by multiplying the reference evapotranspiration (ET_o) by a known crop coefficient (Kc). They use the Penman-Monteith equation (Equation 2) for estimation of reference evapotranspiration.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$ **(Equation 2)**

Where,

ET_o = reference evapotranspiration [mm day^{-1}]
R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]
G = soil heat flux density [MJ m^{-2} day^{-1}]
T = mean daily air temperature at 2 m height [°C]
u_2 = wind speed at 2 m height [m s^{-1}]
e_s = saturation vapour pressure [kPa]
e_a = actual vapour pressure [kPa]
e_s - e_a = saturation vapour pressure deficit [kPa]
Δ = slope vapour pressure curve [kPa $°C^{-1}$]
γ = psychrometric constant [kPa $°C^{-1}$]

Incorporating climate change

Higher air temperature may lead to increases in crop water demand. Table 3-2 and Figure 3-2 can be used with Equation 2 to calculate the likely increase in crop water requirements (by changing T) and thus calculate increasing water requirements for irrigation command areas.

4.2 EXAMPLE APPLICATIONS OF INCREASE IN RAINFALL FREQUENCY AND INTENSITY

a. Example 3 - Design flood estimation with the Rational Formula

Overview and theoretical details

The Rational Formula is widely used to estimate design floods based on rainfall intensity. The method is appropriate for estimating peak discharges for small drainage areas of up to about 200 acres (80 hectares) with no significant flood storage. The method provides a peak discharge value, but does not provide a time series of flow or flow volume.

The Rational Formula estimates the peak rate of runoff at a specific location in a watershed as a function of the drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration (Equation 3).

$$Q = \frac{CIA}{Z}$$ **(Equation 3)**

Where,

Q = maximum rate of runoff (cfs or m^3/sec.)

C = runoff coefficient (see annex 1)

I = average rainfall intensity[2] (in f/hr or mm/hr.)

[2] Rainfall intensity for the design storm (storm duration equal to the watershed time of concentration) is needed to calculate the peak runoff rate

A = drainage area (ac or ha)

Z = conversion factor, 1 for English, 360 for metric

Incorporating climate change

As rainfall intensity increases with climate change, the volume of design floods will also increase. Projected changes in rainfall intensity (

Table 3-5) can be used in the Rational Formula to calculate the increase in design floods due to projected changes in rainfall.

b. Example 4 – Crop production modelling with CROPWAT

As an input to irrigation planning, DOI use the CROPWAT model to estimate crop production. Seasonal and annual rainfall volumes are a key input into the model (Figure 4-1). Therefore the projected changes in seasonal and annual precipitation presented in Table 3-3 could be used in the model to estimate changes in crop production from projected changes in precipitation.

Figure 4-1. Screenshot from CROPWAT model showing input requirements

ETo station: GUANAJUATO-GTO_ Crop: MAIZE (Grain)

Rain station: GUANAJUATO-GTO_ Planting date: 01/04

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	1	Init	0.30	1.73	17.3	3.4	14.0
Apr	2	Init	0.30	1.79	17.9	3.4	14.5
Apr	3	Deve	0.45	2.68	26.8	6.1	20.7
May	1	Deve	0.71	4.31	43.1	7.9	35.1
May	2	Deve	0.98	5.94	59.4	9.8	49.6
May	3	Mid	1.21	7.05	77.6	17.2	60.4
Jun	1	Mid	1.24	6.91	69.1	26.3	42.7
Jun	2	Mid	1.24	6.62	66.2	33.7	32.5
Jun	3	Mid	1.24	6.38	63.8	35.6	28.2
Jul	1	Late	1.17	5.83	58.3	37.8	20.5
Jul	2	Late	0.90	4.28	42.8	40.8	2.0
Jul	3	Late	0.59	2.81	30.9	39.3	0.0
Aug	1	Late	0.38	1.82	5.5	11.2	0.0
					578.7	**272.5**	**320.3**

a. Example 5 – Rainwater harvesting roof size design

Rainwater harvesting design requires estimation of required roof sizes and water storage volumes. DUDBC use a formula based on rainfall and a runoff coefficient for the roof material to estimate the volume of water that will captured by individual rainwater harvesting installations (Equation 5).

Water volume= Annual rainfall x runoff coefficient (roof material) x roof area **(Equation 5)**

The projected changes in annual rainfall provided in Table 3-3 could be used in Equation 5 to estimate the changes in storage volume and roof sizing requirements.

4.3 EXAMPLE APPLICATIONS OF CHANGING FLOWS AND FLOOD FREQUENCIES

a. Example 6 – Channel sizing using the Manning's and Continuity equations

Overview and theoretical details

Most of the GoN infrastructure development departments use the Manning's Equation for uniform flow (Equation 6) and combine with the continuity equation to determine a channel's uniform flow capacity (Equation 7). These equations are used to determine likely flood levels based on cross-sectional area at the design site and the estimated flood discharge.

$$v = \frac{z}{n} R^{2/3} S^{1/2}$$ **(Equation 6)**

Where:

v = Velocity in cfs or m^3/sec

z = 1.486 for English measurement units, and 1.0 for metric

n = Manning's roughness coefficient (a coefficient for quantifying the roughness characteristics of the channel)

R = hydraulic radius (ft. or m) = A / WP

WP = wetted perimeter of flow (the length of the channel boundary in direct contact with the water) (ft or m)

S = slope of the energy grade line (ft/ft or m/m) (For uniform, steady flow, S = channel slope, ft/ft or m/m).

$$Q = \frac{z}{n} A R^{2/3} S^{1/2}$$ **(Equation 7)**

Where,

Q = discharge (cfs or m^3/s)

z = 1.486 for English measurement units, and 1.0 for metric

A = cross-sectional area of flow (sq. ft. or m^2)

R = hydraulic radius (ft. or m) = A / WP

S = slope of the energy grade line (ft/ft or m/m) (For uniform, steady flow, S = channel slope, ft/ft or m/m).

Incorporating climate change

The projected changes in flood discharge provided in Table 3-8 can be used in Equation 7 (to replace Q) and estimate the rise in flood levels that are likely to occur with climate change.

5 DEVELOPMENT SECTOR USE OF MODELLING RESULTS

5.1 IRRIGATION SECTOR

a. Impacts of climate change on the irrigation sector

The following projected changes in climate have been identified as the principal threats to the irrigation sector in Nepal: i) increase in temperature leading to an increase in evapotranspiration rates; ii) changing precipitation altering the effective rainfall and 80% reliable daily events; iii) increasing river flows leading to higher 80% reliable river discharges and 100 year ARI flood discharges; and iv) increasing intensity of rainfall and decreasing return periods leading to an increase in flash floods, storms and landslides[3]. These threats will lead to shifting irrigation demand and supply that will require a change in irrigation planning; and changes in flooding which will require modifications to irrigation infrastructure design.

b. Climate change data for the irrigation sector

Based on the above identified principal threats and impacts identified for the irrigation sector in Nepal, the following climate change information provided in Chapter 3 will be of use to the irrigation sector in developing climate change resilient design and planning:

- Change in air temperature (historical and future projection) for calculation of crop water requirements ;
- Change in annual and seasonal rainfall (historical and future projection) for calculation of crop water requirements and irrigation water volume requirements;
- Change in design flood (historical and future projection) for design of barrages, intakes and other in-stream infrastructure;
- Change in rainfall intensity duration and frequency curve (historical and future projection) for design of barrages, intakes and other in-stream infrastructure;
- Change in sediment transport (historical and future projection) for design of barrages, intakes and other in-stream infrastructure; and
- Change in flows and flow duration (historical and future projection) for canal water management and design of barrages, intakes and other in-stream infrastructure.

c. Application of modelling results in the irrigation sector

Potential applications of the modelling results outlined in Chapter 3 in the work of the irrigation sector include:

- **Crop water requirements**: Projected increases in air temperature (Table 3-2 and Figure 3-2) can be used to determine projected changes in crop water requirements using the approach shown in *Example 2 – Crop water demand*;
- **Design flood estimation from rainfall**: Projected changes in extreme rainfall frequency (Table 3-4 and Table 3-5) will help irrigation engineers to estimate floods using rainfall based formula such as the Rational Method as outlined in *Example 3 - Design flood estimation with the Rational Formula*;

Bed aggradation: Projected changes in total suspended sediment (

[3] DOI and MoSTE (2014) *Irrigation Sector Synthesis Report on Adaptation to Climate Change: Adaptation plan framework for guidelines.*

- Table 3-9) could be used to calculate changing aggradation rates, and thus help to determine placing of intake sites;
- **Irrigation demands:** Changes in annual and seasonal rainfall (Table 3-3) and dependable flows (Table 3-7) can be helpful for irrigation planning;
- **Channel sizing**: Projected changes in flows (Table 3-6 and Table 3-7) can be used to estimate channel sizing to ensure that velocities are kept to an acceptable level, as outlined in *Example 6 – Channel sizing using the Manning's and Continuity equations;*
- **Projected changes in flood recurrence intervals:** Projected changes in flood recurrence intervals (Table 3-8) will impact on design flood volumes and the estimation of scour depth;
- **Crop production:** Changes in annual and seasonal rainfall (Table 3-3) can be applied in the CROPWAT model to estimate change in crop production as described in *Example 4 Crop production modelling using CROPWAT*; and

Sediment trapping: The projected changes in sediment loads (

- Table 3-9) can be used to improve sediment trap sizing and design.

5.2 ROAD AND BRIDGE SECTOR

a. Impacts of climate change on the roads and bridges sector

The strategic and rural road networks in Nepal are highly vulnerable to climate change. Geomorphological systems are dynamic, natural systems are already stressed so that even relatively minor weather events can cause major disturbances. The very nature of the road networks in most parts of Nepal inevitably means that many sections of road cross rivers and streams which are prone to floods and hillsides which are unstable.

The major climate change threats to the strategic and rural road networks in Nepal include: i) increasing total rainfall causing larger riverine floods and higher average river levels; ii) increasing number and intensity of storms causing higher frequency and intensity of rainfall; iii) increasing intensity of rainfall causing more frequent and larger flash floods and debris flows; iv) increasing in the likelihood of Glacial Lake Outburst Floods (GLOF) due to accelerating ice melt and more rainfall; and v) increasing total rainfall and rainfall intensity leading to more frequent landslides[4].

b. Climate change data for the road and bridge sector

Based on the above identified principal threats and impacts identified for the roads and bridges sector in Nepal, the following climate change information provided in Chapter 3 will be essential for the sector in developing climate change resilient designs and planning:

- Change in air temperature (historical and future projection) to assess changes in road and bridge expansion (particularly important for steel bridges);

[4] DOR and MoSTE (2014) *Strategic Road Network Sector Synthesis Report on Adaptation to Climate Change: Adaptation plan framework for guidelines* ***and*** DoLIDAR and MoSTE (2014) *DoLIDAR Local and Rural Roads Network Sector Synthesis Report on Adaptation to Climate Change: Adaptation plan framework for guidelines*.

- Change in design flood (historical and future projection) to calculate changes in scour depths, waterway widths and bridge, road culvert and drainage design;
- Change in Rainfall intensity duration and frequency curve (historical and future projection) will impact on bridge, culvert and drainage sizing and design; and
- Change in sediment transport (historical and future projection).

c. Application of modelling result in Road and bridge

Potential applications of the modelling results outlined in Chapter 3 for design work of the roads and bridge sector include:

- **Bridge expansion:** Projected increases in air temperature (Table 3-2 and Figure 3-2) can be used to determine possible changes in steel bridge expansion as outlined in *Example 1 – Temperature induced longitudinal displacements*;
- **Estimation of floods using rainfall**: Projected changes in extreme rainfall frequency (Table 3-4 and) will help roads and bridge engineers to estimate future floods using rainfall based formula such as the Rational Method as outlined in *Example 3 - Design flood estimation with the Rational Formula*;
- **Sand flow dynamics:** Projected changes in extreme rainfall frequency (Table 3-4 and Table 3-5) can be used to understand short term sediment and sand flow dynamics in rivers, whereas, annual and seasonal rainfall changes (Table 3-3) will be useful to calculate seasonal and annual sediment and sand flow dynamics;

Estimation of bed aggradation: Projected changes in total suspended sediment (

- Table 3-9) combined with projected changes in flows can be used to calculate changing sediment balances and therefore predict aggradation/degradation rates at river crossing and bridge design sites;
- **Projected changes in flood recurrence intervals:** Projected changes in flood recurrence intervals (Table 3-8) will cause changes in design flood volumes and the estimation of scour depth and bridge free-board; and
- **Sediment trapping**: Projected changes in sediment loads can be used to improve culvert sediment trap sizing and design.

5.3 URBAN PLANNING

a. Impacts of climate change on the urban planning sector

The following projected changes in climate have been identified as the principal threats to urban assets in Nepal: i) prolonged high temperatures combining with the heat island effect leading to heat waves that can cause fatalities in urban areas; ii) extreme rainfall events and high rainfall intensities that can cause damage to transport, communication, water supply and sanitation, drainage and power supply networks; and iii) high river flows including the potential for flash flooding that can impact urban areas close to rivers, particularly in low lying areas[5].

[5] DUDBC and MoSTE (2014) *Urban Planning Sector Synthesis Report on Adaptation to Climate Change: Adaptation plan framework for guidelines*

b. Climate change data for the urban planning sector

Based on the above identified principal threats and impacts for the urban planning sector in Nepal, the following climate change information provided in Chapter 3 will be of use to the sector in developing climate change resilient planning and designs:

- Change in flows and flow duration (historical and future projection) will inform the location and zoning of settlements and construction nearby rivers;
- Change in air temperature (historical and future projection) assists in the analysis of the need for urban cooling systems, water supply and city planning;
- Change in annual and seasonal rainfall. (historical and future projection) are useful information for drinking water supply and rainwater harvesting design; and
- Change in dependable flow and seasonal flows will help inform water supply planning.

c. Application of modelling result in urban planning

Potential applications of the modelling results outlined in Chapter 3 in the work of the urban planning and building construction sector include:

- **Estimation of floods using rainfall**: Projected changes in extreme rainfall frequency (Table 3-4 and Table 3-5) will help urban planners to estimate floods for drainage design using rainfall based formula such as the Rational Method as outlined in *Example 3 - Design flood estimation with the Rational Formula*;

Estimation of bed aggradation: Projected changes in total suspended sediment (

- Table 3-9) combined with projected changes in flows can be used to calculate changing sediment balance and therefore predict aggradation/degradation rates at river sections nearby low-lying settlements that are prone to flooding;
- **Storage tank sizing**: Changes in dependence flow (Table 3-7) can be used to estimate required changes in water supply storage tank sizing; and
- **Rainwater harvesting design:** Projected changes in annual and seasonal precipitation (Table 3-3) should be used in the design of roof top rainwater harvesting systems as outlined in *Example 5 – Rainwater harvesting roof size design.*

5.4 WATER INDUCED DISASTER AND GLOF

a. Impacts of climate change on the water induced disaster prevention

The water induced disaster prevention sector is responsible for building structures to protect roads, bridges, irrigation systems, croplands, settlements and schools from water-induced disasters. Due to their nature, they are normally located along riverbanks or floodplains, or on unstable slopes. Therefore all these structures are vulnerable to climate change threats particularly increasing rainfall intensities; flooding and sediment flows.

b. Climate change data for the water induced disaster prevention sector

Based on the above identified principal threats and impacts for the water induced disaster prevention sector in Nepal, the following climate change information provided in Chapter 3 will be of use to the sector in developing climate change resilient planning and designs:

- Change in design flood (historical and future projection) impacts directly on in-stream and on-bank infrastructure design;
- Change in Rainfall intensity duration and frequency curve (historical and future projection) can assist in identification of landslide prone areas; and
- Change in sediment transport (historical and future projection) can assist in the siting of in-stream infrastructure.

c. Application of modelling results in the water induced disaster prevention sector

Potential applications of the modelling results outlined in Chapter 3 in the work of the water induced disaster prevention sector include:

- **Estimation of floods using rainfall**: Projected changes in extreme rainfall frequency (Table 3-4 and Table 3-5) will help water resources engineers to estimate floods for infrastructure design using rainfall based formula such as the Rational Method as outlined *in Example 3 - Design flood estimation with the Rational Formula*;

Estimation of bed aggradation: Projected changes in total suspended sediment (

- Table 3-9) combined with projected changes in flows (Table 3-6 and Table 3-7) can be used to calculate changing sediment balance and therefore predict aggradation/degradation rates at sites identified for infrastructure design;
- **Projected changes in flood recurrence intervals:** Projected changes in flood recurrence intervals (Table 3-8) will cause changes in design flood volumes which will lead to changes in in-stream infrastructure design; and
- **Sediment flow dynamics:** Projected changes in extreme rainfall frequency (Table 3-4 and Table 3-5) can be used to understand short term sediment and sand flow dynamics in river, whereas, annual and seasonal rainfall changes (Table 3-3) will be useful to calculate seasonal and annual sediment and sand flow dynamics.

5.5 WATER SUPPLY AND SANITATION

a. Impacts of climate change on the water supply and sanitation sector

The TA team have identified that water supply and sanitation infrastructure assets are most at risk from: i) the drying-up of water sources and poor groundwater recharge; ii) high intensity and duration rainfall events damaging fragile or weak intake assets; iii) rainfall-induced landslide disruption to water distribution pipelines; and iv) damage to water pumping and treatment plants due to increased temperatures and flooding[6].

b. Climate change data for the water supply and sanitation sector

Based on the above identified principal threats and impacts for the water supply and sanitation sector in Nepal, the following climate change information provided in Chapter 3 will be of use to the sector in developing climate change resilient design and planning:

- Change in flows and flow duration (historical and future projection) will assist in designing intake, channel, piping and storage systems;

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[6] DWSS and MoSTE (2014) *Water Supply and Sanitation Sector Synthesis Report on Adaptation to Climate Change: Adaptation plan framework for guidelines*

- Change in air temperature (historical and future projection) can be used to help identify areas at risk of source depletion and damage to water pumping and treatment plants;
- Change in annual and seasonal rainfall (historical and future projection) can be used to help identify areas at risk of source depletion or future areas for sourcing supplies;
- Change in design flood volumes (historical and future projection) will inform in-stream infrastructure design; and
- Change in rainfall intensity duration and frequency curve (historical and future projection) can assist in the identification of landslide prone areas.

c. Application of modelling results in water supply and sanitation

For proper design of storage reservoir, intakes and distribution system, future climate projections should be taken into account. Potential applications of the modelling results outlined in Chapter 3 in the design work of the water supply and sanitation sector include:

- **Estimation of floods using rainfall**: Projected changes in extreme rainfall frequency (Table 3-4 and Table 3-5) will help water supply and sanitation infrastructure engineers to estimate floods for in-stream and on-bank infrastructure design using rainfall based formula such as the Rational Method as outlined in *Example 3 - Design flood estimation with the Rational Formula*;

Estimation of bed aggradation: Projected changes in total suspended sediment (

- Table 3-9) combined with projected changes in flows (Table 3-6 and Table 3-7) can be used to calculate changing sediment balance and therefore predict aggradation/degradation rates at sites identified for intake or outlet structures;
- **Water supply demands:** Changes in annual and seasonal rainfall (Table 3-3) and dependable flows (Table 3-7) can be helpful for water supply planning and sizing;
- **Projected changes in flood recurrence intervals:** Projected changes in flood recurrence intervals (Table 3-8) will cause changes in design flood volumes which will lead to changes in reservoir, intake and distribution system design; and
- **Sediment trapping**: The projected changes in sediment loads can be used to improve water supply intake sediment trap sizing and design.

ANNEX 1 RUNOFF COEFFICIENTS FOR URBAN WATERSHEDS

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25
Black or loessial soil, 0-3%	0.18-0.25
Black or loessial soil, 3-5%	0.25-0.30
Black or loessial soil, > 5%	0.70-0.80
Deep sand area	0.05-0.15
Steep grassed slopes	0.7
Lawns:	
Sandy soil, flat 2%	0.05-0.10
Sandy soil, average 2-7%	0.10-0.15
Sandy soil, steep 7%	0.15-0.20
Heavy soil, flat 2%	0.13-0.17
Heavy soil, average 2-7%	0.18-0.22
Heavy soil, steep 7%	0.25-0.35
Streets:	
Asphaltic	0.85-0.95

Type of drainage area	Runoff coefficient
Concrete	0.90-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95