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Prepared by
Lahmeyer International in association with Total Management Services Pvt. Ltd.

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Asian Development Bank
IV. EAST RAPTI

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IV. EAST RAPTI RIVER

A. Description

The East Rapti River, which originates from the Mahabharat mountain range in Makwanpur district, is one of the major tributaries of the Narayani River. Flowing southward direction, it changes its course to west near Hetauda and confluences with Narayani River in Chitwan. The location of the river in Nepal is shown in figure below. The area of the basin at the confluence of Narayani is approximately 3108 km$^2$. The main tributaries of the river are: Manahari, Lothar, Riu, Dhongre, Kageri and Kayar. The location map of the river and modeled reach is shown in figure below. The major towns along the study reach are: Hetauda, Bhandara, Sauraha, Bachhaul, Maghaul. The study reach covers Chitwan and Makwanpur districts.

![Figure 1](image_url)

Figure 1 Location map and extent of modeled river reach – East Rapti Basin

East Rapti River is a perennial river with a number of tributaries. The flooding characteristics are dependent on the location of the site and can range from being considered prone to flash flooding in the upper parts of the catchment to a more delayed but sustained flooding in the lower part of the catchment. There has been a history of 143 flood events between 1993 and 2015 of which a significant proportion have caused widespread damage and loss of life. However, as large parts of the basin are part of the Chitwan National Park, there are limited opportunities to carry out large scale flood mitigation measures in these areas.

In recent years, the river has experienced high sediment loads often aggravated by landslides in the upper catchment.
B. Digital Elevation Model (DEM)

The DEM of the basin covering the study reach is shown in Figure 2 below. The DEM is the basis for HEC-RAS geometric data.

![Digital Elevation Model: East Rapti Basin](image)

*Figure 2  DEM – East Rapti Basin*
C. Landuse

**Figure 3** below shows the landuse map for East Rapti Basin. The dominant land use in the study area is forest with a large part being the Chitwan National Park.
D. Soils

The soil map of the basin is given in Figure 4 below. The soils in the Siwalik range have higher erosive potential, from where large amount of sediment are transported to the river.

![Soil map - East Rapti Basin](image)

**Legend**

- **CMe** - Eutric CAMBISOLS
- **CMg** - Gleyic CAMBISOLS
- **CMo** - Ferralic CAMBISOLS
- **CMx** - Chromic CAMBISOLS
- **GLE** - Eutric GLEYSOLS
- **LVx** - Chromic LUVISOLS
- **Pth** - Haplic Phaeozems
- **RGd** - Dystric REGOSOLS

**Figure 4 Soil map – East Rapti Basin**
E. Hydraulic Model

A hydraulic model of the East Rapti River was constructed using the HEC-RAS software. The upstream boundary of the model is located approximately 7 km West of Hetauda along the East-West highway and the downstream boundary is located approximately 0.6 km upstream of the Narayani confluence. The total modeled river length is 96 km and the average slope of the modeled part of the river is 0.0018.

Cross-sections surveyed during the period May-July 2014 were provided by the Client. These were used to construct the HEC-RAS model where suitable. Where necessary, they were extended using the digital elevation model created from CARTOSAT_1 satellite imagery from 2009. A schematic representation of the model is shown in Figure 5 below. The total number of cross-sections considered for the model was 175.

No data was provided for structures across the rivers. It is assumed that any river crossing is of sufficient dimensions so as not to cause any obstructions to flow. This is generally the case for the bridges on the East-West highway which crosses many rivers of the Terai.

Similarly, DWIDP and other agencies have carried out a number of bank protection works and low level flood embankments. These are provided to protect specific local areas and are not part of a comprehensive basinwide flood management program. There is little documentation and field visits suggest that they are often overtopped during the larger floods or breakout floodwaters from upstream still inundate areas behind such structures. They have therefore not been modelled unless they are part of the surveyed cross-sections provided to us.

A value of n=0.03 was taken as the Manning’s roughness parameters for the river channel and n=0.04 for the floodplain area. These values were adopted on the basis of previous modeling experience in the Terai region of Nepal carried out by the Department of Hydrology. Four inflow nodes (Q1, Q2, Q3, Q4) were used to represent the flows generated in the basin and contributions from tributaries. The downstream boundary was represented as a normal flow boundary using the properties of the cross-section at the downstream extent of the model. The hydraulic model was run using hydrographs for the historical 2yr, 5yr, 10yr, 25yr, 50yr and 100yr scenarios. It was also run for climate change scenarios for the 2yr CC, 5yr CC, 10yr CC, 25yr CC, 50yr CC and 100yr CC return periods.
Figure 5  HEC-RAS schematic for East Rapti Basin

F.  Baseline Results

Typical cross-sections in upper reach, mid reach and lower reach for 100 year return period with climate change are shown below.

Figure 6  Typical Cross-section in Upper Reach of East Rapti Basin
Figure 7  Typical Cross-section in Middle Reach of East Rapti Basin

Figure 8  Typical Cross-section in Lower Reach of East Rapti Basin
The longitudinal profiles for 25, 50 and 100 year return periods with and without climate change are shown in figures below.

**Figure 9** Longitudinal Profile for 25 year return period

**Figure 10** Longitudinal Profile for 50 year return period
Figure 11  Longitudinal Profile for 100 year return period

Figure 12  Longitudinal Profile for 25 year plus Climate Change return period
The maximum depth, maximum velocity, timing of peak flow and the value of peak flow for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in figures below.

For the 100 year climate change scenario, the maximum depth varies from 1.2 m to 10.7 m, and the maximum velocity varies from 0.74 m/s to 5.32 m/s. The timing of the peak flow for the 100 year climate change scenario varies from 10 hours in the upstream reaches to 27.5 hours at the outlet. The maximum flow for the 100 year climate change scenario varies from 1610 m$^3$/s in the upstream reaches to 8141 m$^3$/s at the downstream end of the model.

The GIS output of HEC-RAS was exported to HEC-GeoRAS for preparing inundation, velocity and hazard maps.
East Rapti: Maximum Depth

Figure 15 Maximum Depth for Current Conditions

East Rapti: Maximum Depth

Figure 16 Maximum Depth for Climate Change Conditions
Figure 17  Maximum Velocity for Current Conditions

Figure 18  Maximum Velocity for Climate Change Conditions
Figure 19 Time to Peak for Current Conditions

Figure 20 Time to Peak for Climate Change Conditions
Figure 21 Peak Flow under Current Conditions

Figure 22 Peak Flow under Climate Change Conditions

From the first cross-section at the upstream part of the East Rapti River to chainage 80800, the width of the river is small (200m to 800m). The flood plain widens out to 1000m at chainage 89200. Parsa wildlife reserve lies at the left bank of the river from chainage 80000 to 62690.6,
Chitwan National park lies at the left bank from chainage 62690.6 to the last cross-section at downstream. The width of the flood plain at chainage 14198.16 is 650m.

Bankfull discharge of East Rapti in three reaches is given below.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Cross-section</th>
<th>Bankfull flow (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>89800</td>
<td>864</td>
</tr>
<tr>
<td>Mid</td>
<td>53822</td>
<td>1809</td>
</tr>
<tr>
<td>Lower</td>
<td>17358</td>
<td>3317</td>
</tr>
</tbody>
</table>

Inundation maps for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in Figure 32 to Figure 43.

Velocity maps for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in Figure 44 to Figure 55.

The hazard maps for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in Figure 56 to Figure 67. Flood hazard maps have been prepared on the basis of flood hazard ratings described below.

The results of the baseline modelling are given in Table 5 at the end of the report.

G. Hazard Rating

A hazard rating is commonly used to describe the direct risk to people exposed to flood waters. This combines the effect of flood depth and flood velocity with a debris factor. The Hazard Rating formula is given as:

\[ HR = d \times (v + n) + DF \]

where \( HR \) = Hazard Rating
\( d \) = depth of flooding (m)
\( v \) = velocity of floodwaters (m/s)
\( DF \) = Debris Factor
\( n = 0.5 \) (constant)

As the majority of the area modelled is in the Terai region and is predominantly semi-rural or rural in nature, a simplified process which takes account of the relationship between flood depth and debris can be used for defining the debris factor. For this analysis, debris factor (DF) is equal to:

\[ DF = 0.5 \text{ for } d \leq 0.25m \]
\[ DF = 1.0 \text{ for } d > 0.25m \]

Table 2 shows the flood hazard thresholds commonly used to define the degree of flood hazard to people.
Table 2 Flood Hazard Thresholds

<table>
<thead>
<tr>
<th>Threshold for Flood Hazard Rating</th>
<th>Degree of Flood Hazard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.75</td>
<td>Low</td>
<td>Caution — “Flood zone with shallow flowing water or deep standing water”</td>
</tr>
<tr>
<td>0.75 – 1.25</td>
<td>Moderate</td>
<td>Dangerous for some — “Danger: Flood zone with deep or fast flowing water”</td>
</tr>
<tr>
<td>1.25 – 2.0</td>
<td>Significant</td>
<td>Dangerous for most — “Danger: Flood zone with deep fast flowing water”</td>
</tr>
<tr>
<td>&gt; 2.0</td>
<td>Extreme</td>
<td>Dangerous for all — “Extreme danger: Flood zone with deep fast flowing water”</td>
</tr>
</tbody>
</table>

Flood Hazard maps were generated using the above criteria for various return periods.

H. Flood Risk Map

Flood Risk is defined as the product of flood hazard and vulnerability to flooding.

Flood Risk = Flood Hazard x Vulnerability

Whereas the flood hazard is a function of the depth and velocity of flood flows, vulnerability to flooding is generally defined as the characteristics and circumstances of a community, system or asset that makes it susceptible to the damaging effects of a hazard.

From a flooding perspective, and in discussions with DWIDP, it was considered appropriate to categorise flood vulnerability as a function of the landuse which may be exposed to the flood hazard. This would mean that settlements would be more vulnerable to flooding as compared to agricultural land due to the possibility of loss of life and damage to houses. Similarly, cultivated land would be more vulnerable to flooding than forest areas due to economic damage and loss of livelihood and in turn forest areas would be more vulnerable than the river bed.

To account for the population growth in the future and therefore the possible change in settlement areas, the base landuse map needed to be updated.

The definitive data set on location of houses was prepared by the “National Topographic Database Programme” in the 1990s. It is considered as the most comprehensive and also the fundamental dataset available for Nepal (Sharma & Acharya, 2004). A rapid visual assessment of the data was carried out by overlaying the house point data on recent google earth imagery. It was concluded that the data is still representative of the settlement distribution in the project area with settlement clusters reflecting the areas where the population centres are currently located.

The latest census in 2011 (CBS 2014) shows that the Terai population has grown from 8.8 million in 1991 to 13.3 million in 2011; an increase of 4.5 million or almost 51% within 2 decades. It is expected that in 50 years time, in 2066, the population in the Terai will double to 26 million.

However, the pressures on available land will mean that the density of housing will increase, particularly in the urban areas as they will all be required to be accommodated in the same settlement clusters, assuming that the expansion in cultivated land has already reached an optimum level and conservation of forest land will be strictly observed.
To represent the areas occupied by settlements in the future, the point vector GIS house data layer from NTDB 1992 was transformed into raster format with a raster size of 30m to reflect the areas currently inhabited and where future growth may occur. Since almost 100 percent growth of population is expected in the Terai region by 2066, the area of the houses are doubled in size using raster interpolation. This is expected to mimic the settlement growth assuming that the growth will take place in the current settlement area.

The current landuse map from the President’s Chure-Terai Madhesh Conservation Programme Project (2014) was updated by merging the projected 2066 settlement areas on to it. This updated landuse map was used to generate the flood risk maps with the climate change scenario.

The matrix shown in Table 3 was developed to assign appropriate weights to the level of flood hazard (1 to 4) and to the predominant land uses in the study area which would give a measure on a sliding scale of the flood risk score associated with any part of the basin. A sliding scale of 0 to 9 was assigned to the land use from the updated landuse map to reflect the relative vulnerability.

### Table 3 Matrix of Flood Risk Scores

<table>
<thead>
<tr>
<th>Flood Hazard Rating</th>
<th>Flood vulnerability/Societal vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Settlement</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
</tr>
<tr>
<td>Extreme</td>
<td>4</td>
</tr>
<tr>
<td>Significant</td>
<td>3</td>
</tr>
<tr>
<td>Moderate</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
</tbody>
</table>

The flood risk scores are then reclassified into simpler categories to describe the flood risk. Table 4 shows the reclassified flood risk thresholds.

### Table 4 Flood Risk Thresholds

<table>
<thead>
<tr>
<th>Flood Risk Category</th>
<th>Flood Risk Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme/High</td>
<td>&gt;= 9</td>
</tr>
<tr>
<td>Moderate</td>
<td>4 – 8</td>
</tr>
<tr>
<td>Low</td>
<td>&lt;= 4</td>
</tr>
</tbody>
</table>

In discussion with the DWIDP, a flood risk map was generated for the 50 year plus climate change scenario which is the adopted return period for flood mitigation works and this is shown in Figure 104.

### I. Greenbelt

To align with the recent DWIDP Water Induced Disaster Management Policy and taking into account the effects of climate change, a greenbelt has been defined where personal and settlement development would be prohibited and allowable uses would be confined to agriculture, vehicle parking and recreational parks. This reflects the DWIDP aspirations to designate a zone Z1 which is bound by the 5 year return period flood extent. Figure 105 shows the greenbelt area which corresponds to the 5 year plus climate change flood extent.
J. “With Project” Modelling

To protect the flood prone area a number of sites were identified, along the right bank where flood embankments and other mitigation measures would be beneficial. Their locations have been chosen to protect vulnerable areas, particularly near settlements and agricultural land. The location of the embankments and other mitigation measures are shown in Figure 23.

Figure 23 Location of Proposed Embankments in East Rapti

Embankments were modelled as glass walls and the DEM along the embankment line was modified accordingly. The "with project" model was run for the various scenarios and the results are shown below.
Figure 24 Maximum Depth “With Project” for Current Conditions

Figure 25 Maximum Depth “With Project” for Climate Change Conditions
Figure 26 Maximum Velocity “With Project” for Current Conditions

Figure 27 Maximum Velocity “With Project” for Climate Change Conditions
Figure 28  Time to Peak “With Project” for Current Conditions

Figure 29  Time to Peak “With Project” for Climate Change Conditions
For comparison with and without project, plots of water levels and maximum velocity for the 50 year plus climate change scenario used for design of such embankments are shown in the figures below. As would be expected, the water level and velocity rises in the vicinity of the embankments due to reduced cross-section as the extent of the flood plain is confined within the embankment. The effects do not propagate a lot further downstream.

**Figure 30** Change in Maximum Water Levels for 50 year plus climate change scenario

**Figure 31** Change in Maximum Velocity for 50 year plus climate change scenario

**Table 6** shows the results for the with project scenario.

**Figure 23** shows the difference in 50 years plus climate change flood extent as compared to the baseline scenario.
Inundation maps for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in Figure 68 to Figure 79.

The velocity maps for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in Figure 80 to Figure 91.

The hazard maps for 2, 5, 10, 25, 50 and 100 year return periods with and without climate change are shown in Figure 92 to Figure 103. Flood hazard maps have been prepared on the basis of flood hazard ratings described previously.