FLOOD HAZARD ASSESSMENT FOR PUNAKHA DZONGKHAG

FLOOD ENGINEERING AND MANAGEMENT DIVISION,
DEPARTMENT OF ENGINEERING SERVICES
MINISTRY OF WORKS AND HUMAN SETTLEMENT

YEAR 2019

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Acknowledgment

Flood Engineering and Management Division under Department of Engineering Services, Ministry of Works and Human Settlement would like to thank the Dzongkhag Administration and local government of Punakha Dzongkhag for Mochu, Phochu and Toebrongchu in Punakha Dzongkhag. We would also thank the following organizations for the data and support provided.

1. Dzongkhag Administration and Local Government, Punakha Dzongkhag
2. National Centre for Hydrology and Meteorology, Ministry of Economic Affairs, Bhutan
3. National Statistical Bureau, Bhutan

Acronyms

FEMD	Flood Engineering Management Division.
HEC-RAS	The Hydrologic Engineering Center, River Analysis System is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modelling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.
AoMI	Areas for Mitigation Interest
DDM	Department of Disaster Management.
DES	Department of Engineering Services
MoWHS	Ministry of Works and Human Settlement

Executive Summary

Flooding in Punakha Dzongkha is mainly caused by Mochu, Pochu and the Punatsangchu. The settlements and important historical structures are all located along the right bank of Mochu thus exposing them to high flooding risk. Left bank of Mochu lies the higher elevation hills thus exposed to low risk of flooding.

The left bank of Phochu is mainly used as paddy fields by the residents living along phochu and is exposed to high erosion since the velocity of Phochu is higher than the Mochu. The right bank of Phochu is mostly the hills with low flooding risk.

The objective of the study was to conduct a detailed flood assessment of critical rivers in Punakha Dzongkhag. And after analysing the AoMI, prioritize critical flood prone areas; recommend appropriate flood protection measures along the identified flood prone areas.

A detailed field investigation was conducted and the areas with high flood risks were identified. Among all the Gewogs in Punakha Dzongkhag, Guma Gewog is exposed to the highest risk since most the settlement is along Mochu. And Baarp Gewog is exposed to the least flooding risk while the other Gewogs were exposed to medium flooding risk at certain locations.

The Punakha Dzongkha with technical support from FEMD, DES, MoWHS have been working towards managing flooding issues along Mochu from the last few years. In the fiscal year FY 2014-15, FEMD, Department of Engineering Services provided the technical backstopping like design, estimate and drawing with specifications to Punakha Dzongkhag and the flood protection works were executed in two packages. The 1st package was the Rip Rap Boulders along Changyul House and Sonagasa Palace road which was done by the Dzongkhag Departmentally. The 2nd package was the Gabion Revetment along Mochu, upstream of Changyul Bridge which was executed on Contract basis. Both the works have been completed by the end of 2015.

Introduction

Background

The Punakha Dzongkhag is situated in the Western Bhutan bordering Gasa Dzongkhag to the North, Thimphu to the west and Wangdue Phodrang to the south eastern part. The Dzongkhag is located at the altitude ranging from 1100 to 2500m above sea level. The temperature of Punakha Dzongkhag is about 32° C in summer and 12°C and maximum of 19°C during winter. Punakha Dzong served as the winter capital of Bhutan until 1955, but currently serves as a winter residence for the Central Monastic Body. The total Geographical area of the Dzongkhag is approximately1109.81 Sq.km.

The Punakha Dzongkhag consists of 11 Gewogs and provide administrative support for all the Gewogs, namely Baarp, Chhubu, Dzomi, Goenshari, Guma, Kabjisa, Lingmukha, Shengana, Talo, Toepisa and Toedwang

The major crops cultivated in the area are paddy, Vegetables and fruits owing to its favourable climate conditions. The Dzongkhag basically cultivates little of every crops but the main crops are paddy, wheat, maize and mustards. The farmers grow citrus like guavas, peaches, plums, pears, avacado, apricots etc. The Dzongkhag also grows variety of vegetables like chillies, radish, cabbages, brinjals, and tomatoes. Favourable terrain and climatic conditions combined with fertile agriculture land offer tremendous opportunity for farm mechanization and commercial horticultural development.

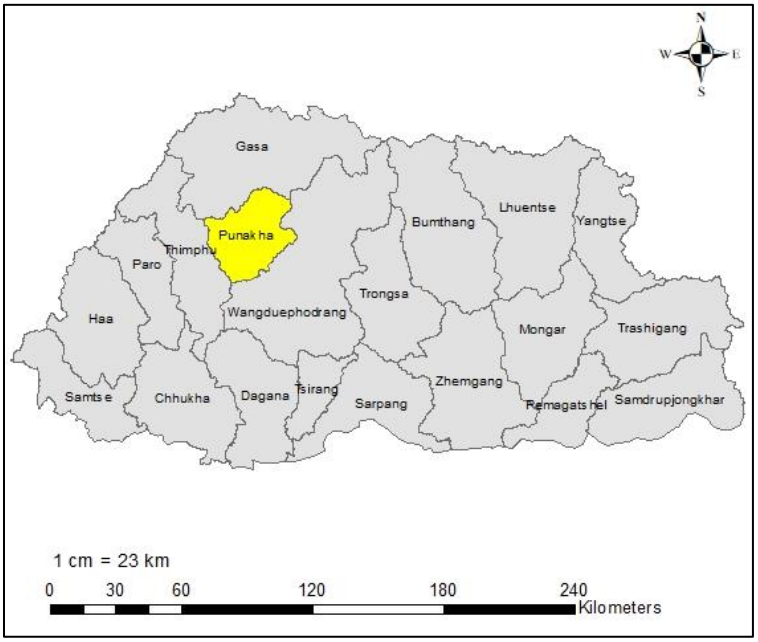

Figure 1: Location of the study area

The climate in Punakha Dzongkhag is hot, humid sub-tropical climate with an elevation ranging from 1100 to 2500m above the mean sea level. The temperature of Punakha Dzongkhag is about 32° C during the summer and 12°C with maximum of 19°C during the winter season. Around 75.87 % of its land is under forest cover mostly consisting of the broad leaf subtropical evergreen trees. The winter season is moderately cool and comfortable whereas summer season is hot and humid.

Objective

Objective 1: Detailed flood assessment of critical rivers in Punakha Dzongkhag.

Objective 2: Analyze the AoMI (Areas of Mitigation Interest) assessment in Punakha Dzongkhag. Furthermore, identify and prioritize critical flood prone areas within Punakha Dzongkhag.

Objective 3: Recommend appropriate flood protection measures along the identified flood prone areas.

Study Area

Kabjisa Gewog

Kabjisa Gewog stretches over an area of 206.1 sq. km as per LCMP 2010 with an altitude ranging from 1300-1800 m above sea level. There are 447 households in the Gewog, which currently hold a population of 2361 people. The Gewog comprises of five chiwogs and has five tshogpas. The Gewog has a very fertile land and all varieties of cereal crops are grown. Orange and sweet potato are grown as cash crops. Settlements are largely concentrated on the right bank of the Mo chhu River. Sub-tropical climate and favourable terrains offer tremendous opportunity for farm mechanization.

Guma Gewog

Guma Gewog stretches over an area of 37sq.km as per LCMP 2010 with an altitude ranging from 1200-2200 m above sea level. There are 816 households, which currently hold a population of 4288 people. Settlements are quite dense in this Gewog due to its proximity to Khuruthang town and Punakha Dzong.

Guma Gewog falls under the sub-tropical zone. There is chirpine forest at the lower altitude and mixed warm broad leaf forest at the higher levels. Summers are hot with temperature reaching almost 32 degree Celsius. In winter, the minimum is 12 degree Celsius and maximum of 19 degree Celsius. Land turns dry and is windy with occasional frost in the morning. Almost all varieties of crops (Dhunaghu) are grown in the Gewog, but importance is given to paddy cultivation. Various vegetables and fruits are also grown and the surpluses are sold in the market. The main source of income is from the livestock products.

Toedwang Gewog

Toedwang Gewog stretches over an area of 415.65 sq. km as per LCMP 2010 with an altitude ranging from1250-3700m above sea level. There are 454 households in the Gewog, which currently hold a population of 2421 people. The Gewog experiences cool winters with warm and humid summers. The cooking oil "PangtseMakhu" is produced in this Gewog and people earn income from the sale of "makhu" as well as rice.

Dzomi Gewog

Dzomi Gewog is located in between Shengana and Lingmukha Gewogs with an altitude ranging from 1200-2400 m above sea level. It stretches over an area of 21.92 sq. km as per LCMP 2010. There are 257 households in the Gewog, which currently hold a population of 1350 people. It is accessible by motor-able road and due to its proximity to Khuruthang town; people of the Gewog can market their agricultural and livestock products easily. The Gewog has high potential for production of paddy, wheat, mustard and horticultural crops.

Toebisa Gewog

Toebisa Gewog was under Thimphu Dzongkhag until it was merged to Punakha Dzongkhag during the year 2008. The total area of the Gewog is 102.8 sq.km (approx) as per LCMP 2010 with the elevation ranging from 1709 m to 3200 m above mean sea level. Since the East-West highway passes through the Gewog, people can market their produce easily and to facilitate this there are several market sheds constructed along the highway. The Gewog lies in sub-tropical region like Baarp Gewog with hot and humid summers and cold winters. Almost all the households of this Gewogs earn cash income from the sale of fruits, vegetables and rice.

Baarp Gewog

The Baarp Gewog is about 12KM from Punakha Dzongkhag and is observed as one of the most accessible Gewogs among others. Paddy is the principle cereal crop in the Gewog followed by spring wheat. Almost all the households of this Gewogs earn cash income from the sale of fruits, vegetables and rice. The fertile Lobesa valley offer promising opportunity for farm mechanization. Baarp Gewog covers an area of about 24.6 sq.km (approx.) as per LCMP 2010 with elevations ranging from 1400 meters to 1800 meters above mean sea level. The Gewog experiences an annual rainfall of about 500mm-1500mm approximately with the temperature ranging from 5^0C-30^0C.

Methodology

The methodology adopted for the study is as shown in Figure 2. A thorough desktop study was followed by data collation from different agencies. A detailed site assessment was conducted in coordination with the leaders of the Local Government of Punakha Dzongkhag and the Areas of Mitigation Interest (AoMI) were identified and prioritized.

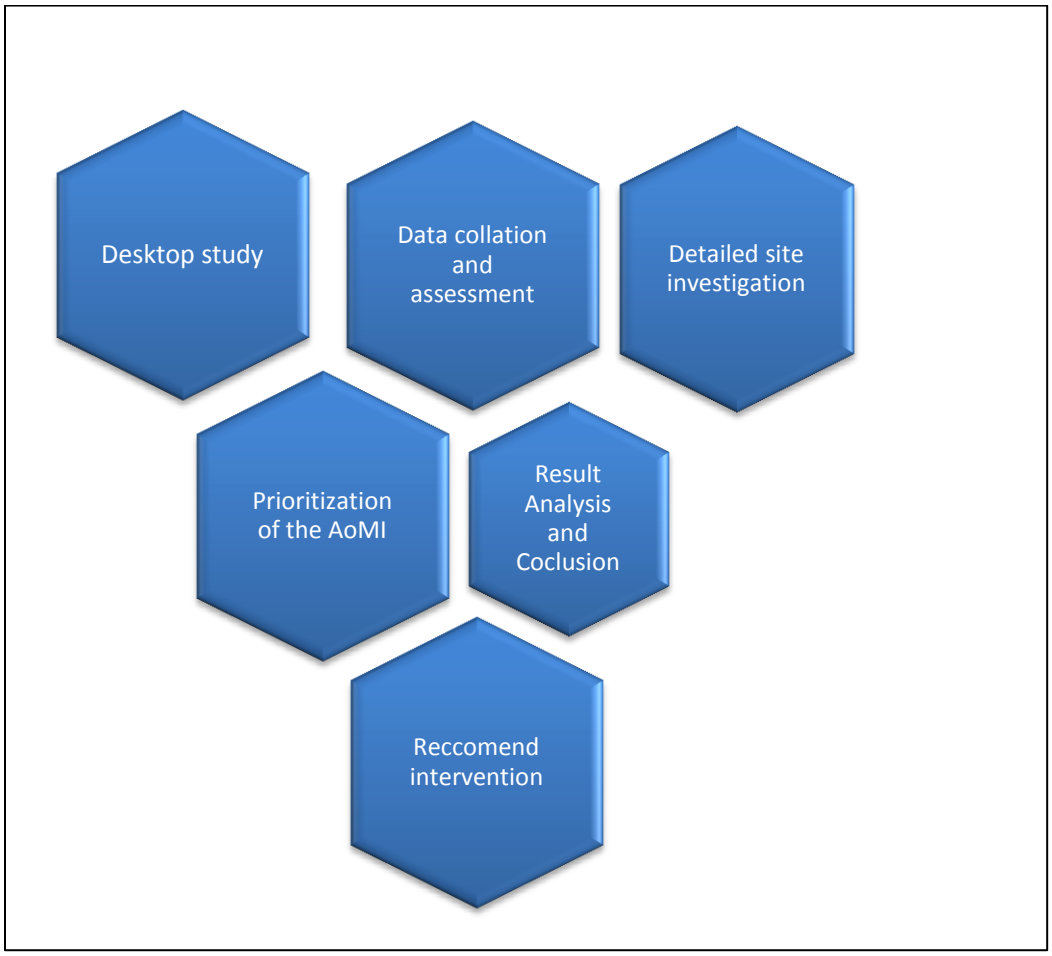

Figure 2: Methodology adopted for the study

Data Collection and Assessment

Hydrological and Meteorological Data

The hydro-meteorological data was acquired from the National Centre for Hydrology and Meteorology (NCHM). As per the data from NCHM, there are five meteorological stations and two hydrological station as shown in Figure 3.

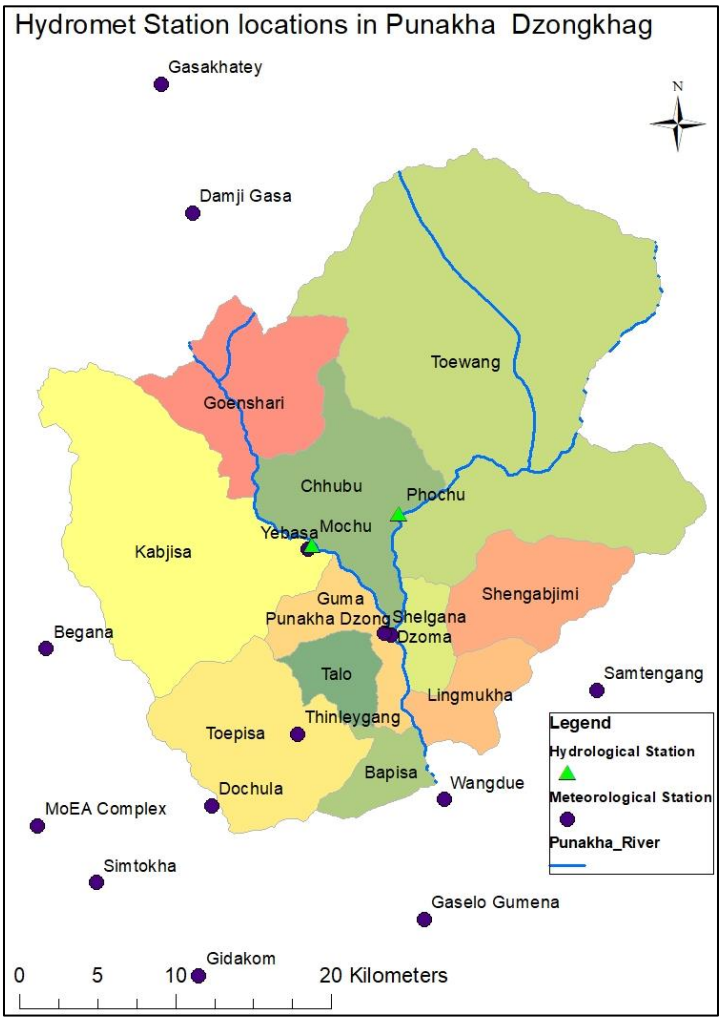

Figure 3: Hydro-Meteorological station in the study area

Site Assessment at Gewog Level

A detailed Gewog level flood assessment was conducted for the 6 Gewogs exposed to flooding risk using the flood assessment forms. During the survey, the team inspected the potential flood risk sites and collected basic land Geographical data, demographic data (the number of households under the risk etc.) and past flood event records with the cooperation of local

Gewog's officials. The whole site is walked thoroughly to see any particular points of interest while carrying out the preliminary flood hazard assessment studies.

Kabjisa Gewog

During the assessment, critical areas which are exposed to flooding under Kebjisa Gewog are identified as listed in Table 1.

Table 1: Flood prone areas in Kabisa Gewog

Sl.No	Name of the Villages/Rivers	Gewog	Coordinates		Elevation	Remark
			Easting	Northing		
1	Wanakha village	Kabjisa	89°46'35.60"	27°38'49.10"	1353	Low Risk
2	Serigang village	Kabjisa	89°48'9.40"	27°38'6.70"	1305	Medium Risk
3	Below Zangtogpelri village	Kabjisa	89°49'5.30"	27°37'47.5"	1267	Low Risk
4	Yebesa and Sonagasa palace	Kabjisa	89o49'5.30"	27o37'47.5"	1267	High Risk
5	Sonagasa old Zoo	Kabjisa	89°50'53.5"	27°36'26"	1229	High Risk

Figure 4: Wanakha village in Kabisa Gewog

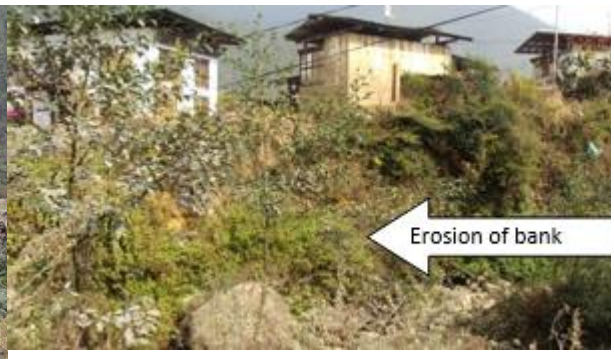

Figure 5: Bank erosion along settlement in Serigang village

Figure 6: Village below Khamsum Yulay Namgyel Chorten (Left bank of Mochu).

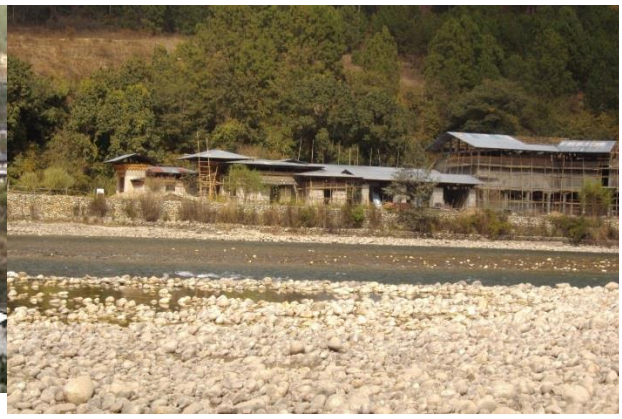

Figure 7: Left bank of Mochu between Yebesa and Sonagasa palace

Figure 8: Sonagasa old zoo at the left bank of Mochu

Guma Gewog

During the assessment, critical areas that are exposed to flooding under Guma Gewog are identified as listed in Table 2.

Table 2: Flood prone areas in Guma Gewog

Sl.No	Name of the Villages/Rivers	Gewog	Coordinates		Elevation	Remarks
			Easting	Northing		
1	Zomlingthang	Guma	89°51'14.9"	27°36'1.6"	1226	High Risk
2	Downstream of Zomlingthang	Guma	89°51'39.6"	27°35'20.7"	1222	High Risk
3	Changyuel	Guma	89°51'39.6"	27°35'20.7"	1221	High Risk
4	Below Lekithang.(PHSS)	Guma	89o52'2.3"	27o34'37.9"	1220	High Risk
5	Khuruthang.(Near TTI)	Guma	89o52'24"	27o33'13.20"	1215	High Risk

Figure 9: Zomlingthang at the right bank of Mochu

Figure 10: Area opposite to Zomlingthang at the left bank of Mochu

Figure 11: Changyel at the right bank of Mochu

Figure 12: Right bank of Punatsangchu below Punakha High School

Figure 13: Khuruthang at the right bank of Punatsangchu

Toedwang Gewog

During the assessment, critical areas which are under the threat from erosion due to flooding under Toedwang Gewog are identified as listed in Table 3.

Table 3: Flood prone areas in Toedwang Gewog

Sl.No	Name of the Villages/Rivers	Gewog	Coordinates		Elevation	Remarks
			Easting	Northing		
1	Samarzingkha	Toedwang	89°51’52.8”	27°37’58.9”	1258	Medium Risk
2	Khawakha	Toedwang	89°52’5.7”	27°37’24.7”	1248	Medium Risk

Figure 14: Samarzingkha at the right bank of Phochu

Figure 15: Khawakha at the right bank of Phochu

Dzomi Gewog

During the assessment, critical areas which are under the threat from erosion due to flooding under Dzomi Gewog are identified as listed in Table 4.

Table 4: Flood prone areas in Dzomi Gewog

Sl.No	Name of the Villages/Rivers	Gewog	Coordinates		Elevation	Remarks
			Easting	Northing		
1	Tsekathang	Dzomi	89 °52’27”	27°36’20.7”	1246	Low Risk
2	Shangalungchu	Dzomi	89 °52’22”	27°35’31.3”	1223	Medium Risk
3	Mendagang(opposite to Lingkana)	Dzomi	89 °52’7.7”	27°34’59.4”	1221	Medium Risk

Figure 16: Tsekathang at both banks of Phochu

Figure 17: Shengalungchu at the left bank of Phochu

Figure 18: Mendagang at the left bank of Phochu

Toebisa Gewog

During the assessment, critical areas which are under the threat from erosion due to flooding under Toebisa Gewog are identified as listed in Table below:

Sl.No	**Name of the Villages/Rivers**	**Gewog**	**Coordinates**		**Elevation**	**Remarks**
			Easting	**Northing**		
1	Toebisa	Toebisa	89°50'29.9"	27°31'45.9"	1400	Low Risk

Baarp Gewog

During the assessment, critical areas which were exposed to flooding under Baarp Gewog are identified as listed in Table 5.

Table 5: Flood prone area in Baarp Gewog

Sl.No	Name of the Village/area	Gewog	Coordinates		Elevation	Remark
			Easting	Northing		
1	Soksokha Village Hotel	Baarp	89°51'58"	27 °31'35.4"	1248	High Risk
2	Below Soksokha Village	Baarp	89°52'13.1"	27°31'33.2"	1243	Low Risk
3	Downstream of Chimi Lhakhang	Baarp	89 °52'27.1"	27o31'43"	1219	Low Risk

Figure 19: Soksokha village at the left bank of Toebrongchu

Figure 20:Downstream of Soksokha village at both the banks of Toebrongchu

Figure 21: Below Chimi Lhakhang at both banks of Toebrongchu

Flood Frequency Analysis

Gumbel Distribution

Gumbel is an Extreme Value distribution (EV Type I) (Emil Julius Gumbel, 1941) used to analyse extreme maximum or minimum of a number of sample of distribution. The parameters for the distribution are as follows. The mean (μ) and the standard deviation (σ) of the annual maximum time series is computed along with values of 'a' and 'c' which is given by Eqn. 1 and Eqn. 2.

$$a = \sqrt{\frac{6\sigma^2}{\pi^2}} = 0.7797\sigma \qquad \text{Equation 1}$$

$$c = \mu - 0.5772a \qquad \text{Equation 2}$$

And for each return period of (T), the standard variate is computed using Eqn.3 and the return period discharge is computed using Eqn.4.

$$Y_T = -\ln\left[-\ln\left(1-\frac{1}{T}\right)\right] \qquad \text{Equation 3}$$

$$Q_T = c + Y_T a \qquad \text{Equation 4}$$

The return period discharge computed using Gumbel distribution for Punatsangchu is shown in Figure 22.

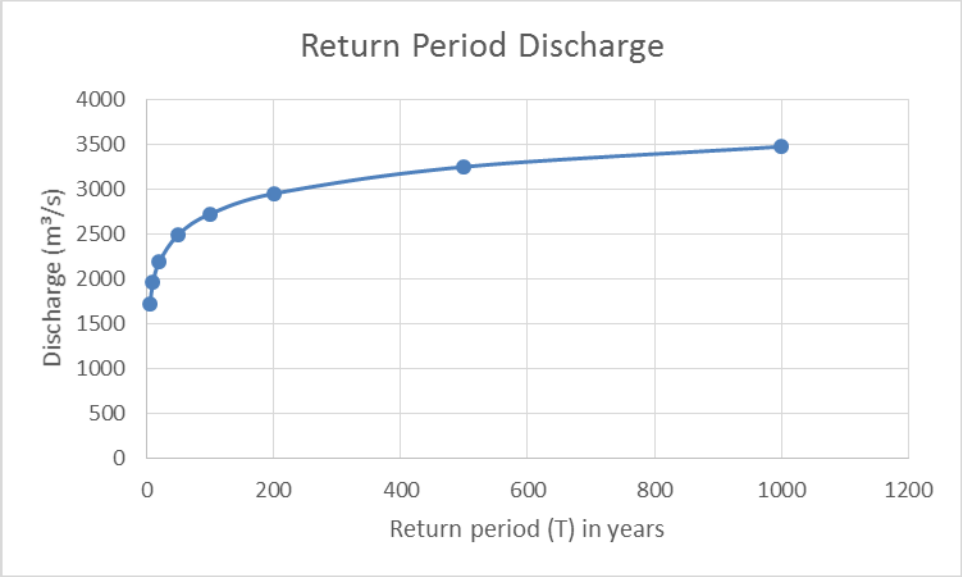

Figure 22: Return period discharge for Punatshangchu using Gumbel method

Log Pearson III distribution

The Log Pearson III (Pearson, 1895) statistical technique was used to fit the flood frequency for the River. The distribution is computed by a general equation, Equation 5. The annual peak

discharge data were ranked from largest to smallest and the $\log_{10}$ value for each data was computed. The return period discharge computed using Gumbel distribution for Punatsangchu is shown in Figure 23.

$$\log_{10} Q_T = K_T \sigma + \mu \qquad \text{Equation 5}$$

Where Mean, $\mu = \frac{1}{n}\sum_{i=1}^{n}(\log_{10}(x_i))$

Standard deviation, $\sigma = \frac{1}{n-1}\sum_{i=1}^{n}(\log_{10}(x_i) - \mu)^2$

Probability of occurrence, $P_T = \frac{1}{T}$

Intermediate variable w for each return period, $w_T = \left[\ln\left(\frac{1}{P_T^2}\right)\right]^{\frac{1}{2}}$ *for* $(0 < P_T \leq 0.5)$

Frequency factor $K_T = Z_T + (Z^2{}_T - 1)k + \frac{1}{3}(Z^3{}_T - 6Z_T)k^2 - (Z^2 - 1)k^3 + Z_T k^3 + Z_T k^4 + \frac{1}{3}k^5$

$$k = \frac{C_s}{6};\ C_s = \frac{n\sum_{i=1}^{n}(\log_{10}(x_i) - \mu)^3}{(n-1)(n-2)\sigma^3}$$

$$Z_T = w - \frac{2.515517 + 0.0802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}$$

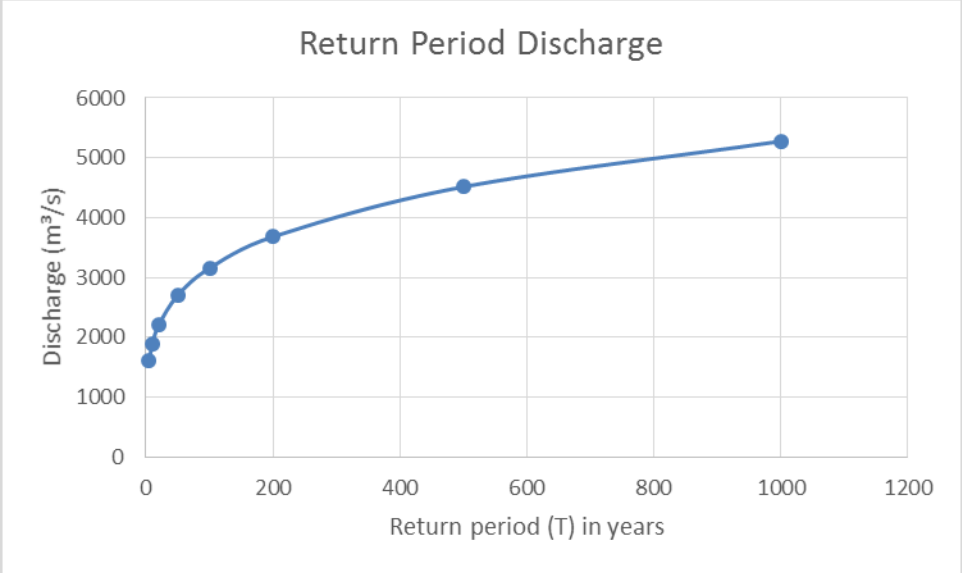

Figure 23: Return period discharge for Punatshangchu using Log Pearson III

Result Analysis and Conclusion

Flooding in Punakha Dzongkha is mainly caused by Mochu, Pochu and the Punatsangchu. The settlements and important historical structures are all located along the right bank of Mochu thus exposing them to high flooding risk. Left bank of Mochu lies the higher elevation hills thus exposed to low risk of flooding.

The left bank of Phochu is mainly used as paddy fields by the residents living along phochu and is exposed to high erosion since the velocity of Phochu is higher than the Mochu. The right bank of Phochu is mostly the hills with low flooding risk.

It has been proven that any bank protection structure constructed with have an erosive effect on the opposite bank. This kind of river morphology was seen in Mochu as well. In the left bank of Mochu lies one of the most historic Dzong, the Punakha Dzong. A huge investment was made to protect the left bank of Mochu upstream of the Dzong to protect it from being flooded. Although the flood walls have been successful in protecting the left bank, the residents have observed an increase in the erosion rate of Mochu at the right bank. And as per the measurement from Google earth images shown in Figure 24, the rate of erosion at right bank of Mochu from 2012 to 2014 was negligible while the rate of erosion over a span of 2 years (from 2014 to 2016) is approximately 15 m. The change in the floodplain width at two selected locations can be seen in Table 6. One of the reasons for the increased erosion could be the bank protection wall that was constructed along the left bank of Mochu in 2015.

Figure 24: Google image showing the erosion at the right bank of Mochu in a span of 2 years (2014 and 2016)

Table 6: Change in floodplain width along right bank of Mochu

Location	Length in 2014	Length in 2016	Difference
Location 1	61.9m	47.4m	14.5m
Location 2	71.1m	55m	16.1m

Among all the Gewogs in Punakha Dzongkhag, Guma Gewog is exposed to the highest risk since most the settlement is along Mochu. And Baarp Gewog is exposed to the least flooding risk while the other Gewogs were exposed to medium flooding risk at certain locations. The area with the highest risk is depicted in Figure 25.

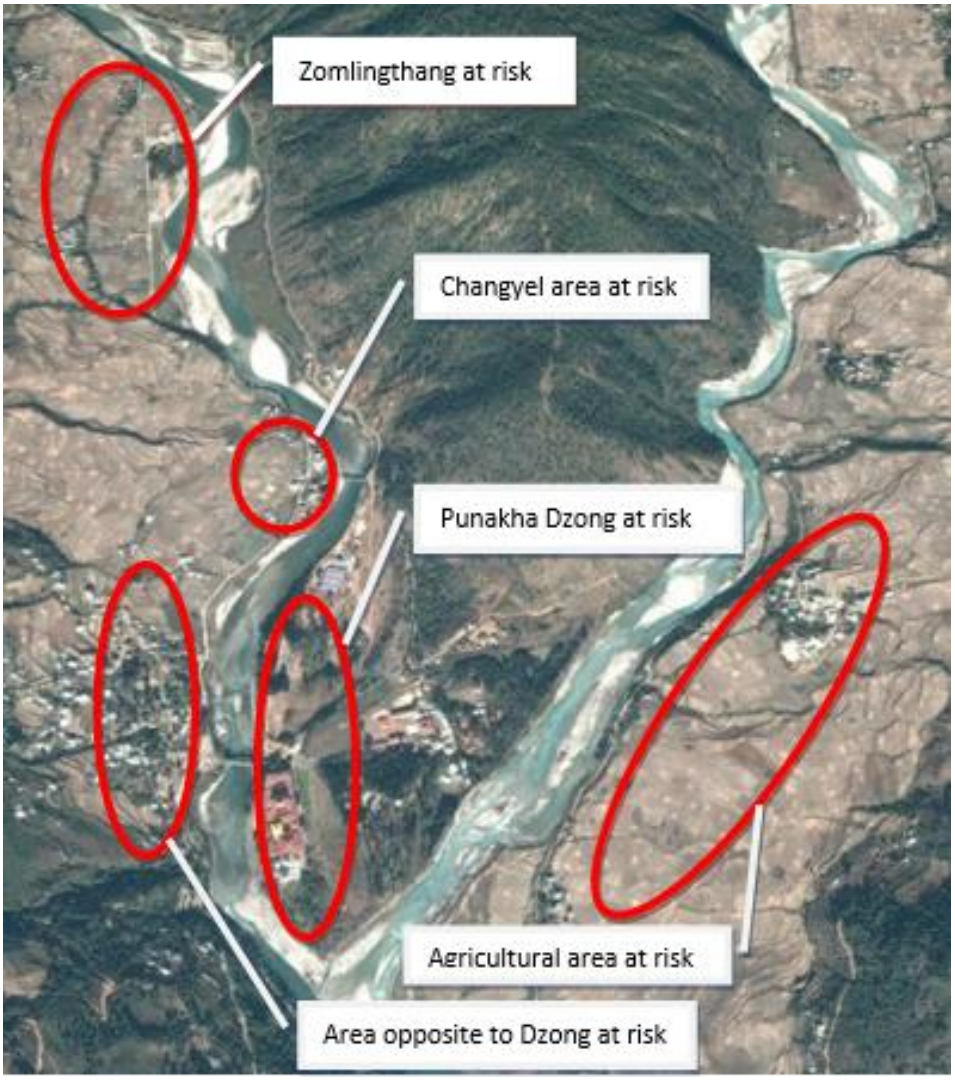

Figure 25: The areas with the highest flooding risk in Punakha Dzongkhag.

Recommendation for flood management

Prioritization of the AoMI has been identified through the site investigation and the data analysis though the study. The details of the prioritized areas are mentioned in the previous chapter. The following are the list of AoMI in order of priority:

1. Near (TTI) Technical Training Institute and vegetable market in Guma Gewog
2. Changyel at the right bank of Mochu in Guma Gewog
3. Zomlithang at the right bank of Mochu in Guma Gewog
4. Downstream of Zomlithang at the left bank of Mochu in Guma Gewog
5. Yebesa and Sonagasa palace at the left bank of Mochu in Kabisa Gewog
6. Sonagasa old Zoo at the left bank of Mochu in Kabisa Gewog
7. Soksokha village Hotel at the left bank of Toebroncghu in Baarp Gewog
8. Serigang in Kabisa Gewog
9. Samazingkha and Khawakha in Toedwang Gewog
10. Shangalungchu and Mendagang in Dzomi Gewog

The flood interventions for the prioritised area are detailed in the next chapter of intervention. The Dzongkhag administration is recommended to carry out the flood protection works with technical support from the Flood Engineering and Management Division, DES, MoWHS,

The Department of Disaster Management, Ministry of Home and Cultural Affairs, is recommended to carry out the pre-disaster activities in the identified flood prone areas. The DDM can work in collaboration with the Local Government to locate the exact settlements from the FHM and plan the flood disaster awareness campaign in the areas.

Interventions

Design of the structures are required for effective and sustainable flood mitigation and bank protection of River to protect the lands, properties, human lives and infrastructures along the bank of the rivers. Sustainability of the flood and bank protection works in the river bed depends on sound design of the protection works. The protection will establish equilibrium flow regime and prevent the banks from eroding and overtopping. The design process is as follows:

- Interpreting the results of the mathematical model studies and field assessment studies.
- Design of river training works according to the type of flooding problem (erosion, overflow or sediment related problems).

Layout of structural measure in critical Gewogs

Gewog	**Village**	**Stream/River name**	**Length of structure**	**Type of structure recommended**
Kabisa	Serigang	SeriRongchu	200 m	Gabion revetment with apron
Guma	Zomlithang	Right bank of Mochu	1500 m	Rip Rap
	Downstream of Zomlithang	Left bank of Mochu	2000 m	Rip Rap
	Changyel (downstream of Changyel Bridge till the Dzong)	Right bank of Mochu	500m	Gabion revetment with apron
	Below Punakha High School	Right bank of Punatsangchu	150m	Gabion revetment with apron
	Near (TTI) Technical Training Institute and vegetable market	Right bank of Punatsangchu	Between the existing flood protection walls	Gabion revetment with apron
Toedwang	Samarzingkha	Right bank of Phochu	250m	Gabion revetment with apron

	Khawakha village	Right bank of Phochu	200m	Gabion revetment with apron
Dzomi	Shangalungchu	Left bank of Phochu	Not measured	Gabion revetment with apron
	Mendagang(opposite to Lingkana)	Left bank of Phochu	Not measured	Gabion revetment with apron
Baarp	Soksokha(Village Hotel)	Left bank of Toebrongchu	Not measured	Gabion revetment with apron

The Punakha Dzongkhag had requested the Ministry of Works and Human Settlement to incorporate budget for flood protection works in the Dzongkhag for the 2nd FY of the 11th FYP as per letter No. DAP/ENG-10/2013-14/423 dated 7th March, 2014. Accordingly, the Ministry allotted a total budget of Nu. 10 Million for flood protection works along Mochu for FY 2014-15. The FEMD, Department of Engineering Services provided the technical backstopping like design, estimate and drawing with specifications to the Dzongkhag and the flood protection works were executed in two packages. The 1st package was the Rip Rap Boulders along Changyul House and Sonagasa Palace road which was done by the Dzongkhag Departmentally. The work was completed on 30/06/2015 and the total cost incurred was Nu. 5,663,559.05. The before and after intervention image can be seen in Figure 26 and Figure 27.

The 2nd package was the Gabion Revetment along Mochu, upstream of Changyul Bridge which was executed on Contract basis. The work was completed on 30/06/2015 and the total cost incurred was Nu. 4,336,450. The before and after intervention image can be seen in Figure 29 and Figure 30.

Rip Rap structure

Rip rap is the name given to loose rock armor used for river bank protection. The rip rap covers the bank with a layer of stones of varying sizes. The sizes of the stones used depend upon the velocity of the flowing river. The stones can be hand placed or machine installed depending upon the size of area to be stabilized, accessibility of the machines for placing the stones and requirement of more natural arrangement of stones.

Advantages

- Easy to install in general and it can even be placed under water.
- High hydraulic roughness to reduce the force of waves and current.
- The maintenance cost of riprap is low and easy to repair.
- It is durable and highly flexible allowing it to settle into underlying soil contour.
- It is aesthetically pleasing to look at blending in with the natural environment.
- It is resistance to scour and there is no issue of hydrostatic pressure.
- It can experience minor damage and still continue to function.

Disadvantages

- The rip rap requires skilled labor during construction.
- It is expensive to use rip rap as the large stones have to be quarried and transported from long distances.
- Large stones used for rip rap on steeper slopes will be prone to falling down and thus, dangerous.
- Smaller rip rap stones has the chances of being vandalized.

Figure 26: Near Changyel area before intervention in 2014

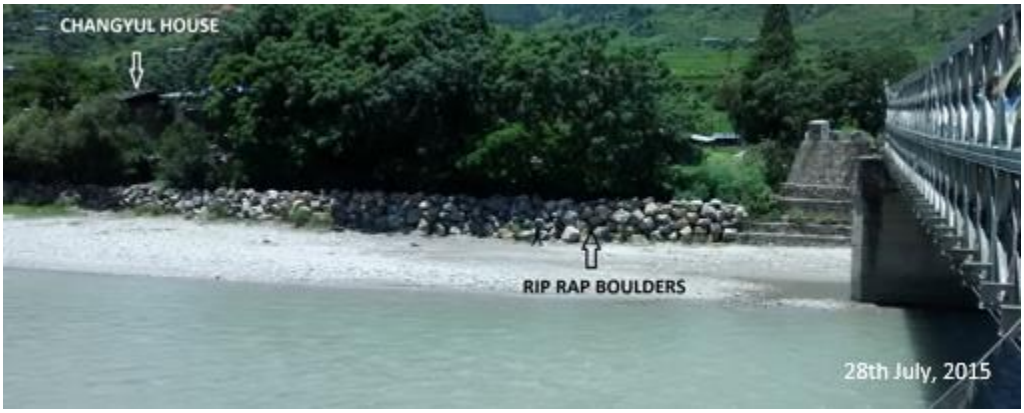

Figure 27: Near Changyel area after intervention in 2015

Gabion revetment

The earthen embankments are constructed along the river banks within the flood plains of a river. The embankments are constructed to confine the river flood water within the cross- section available between the embankments preventing it from spilling over to the flood plains. This type of flood protection against flooding has been provided in some flood prone rivers with low banks in Bhutan. To prevent the erosion of the earthen embankments, it is further protected by constructing revetments on the riverside of the embankment. When the revetment is constructed with gabion mattress filled in with stones, it is called gabion revetment. A typical cross section of a gabion revetment is shown in Figure 28.

Advantages of gabion revetment

1) Can be used as path by the pedestrian beside river.
2) The construction materials for this type of flood protection structure are easy to transport and use at site. (Stones, soils and gabion mattresses)
3) It can conform to subsidence as it can move with the earth and also dissipate energy from flowing water.

4) Their permeability allows the gabion baskets to drain water easily reducing the pore pressure.
5) They are environmentally friendly (green alternative) and requires no special masonry or skilled labour to construct it.

Disadvantages of gabion revetment

1) Aesthetically not pleasing to sight.
2) When the velocity of the streams and rivers are high, the gabion mesh baskets are at risk of getting torn by the transported boulders or debris.
3) The gabion baskets are at risk of being damaged by corrosion if high quality gabion baskets are not used
5) Upon failure of the gabion revetment, the earthen embankment can be easily eroded.

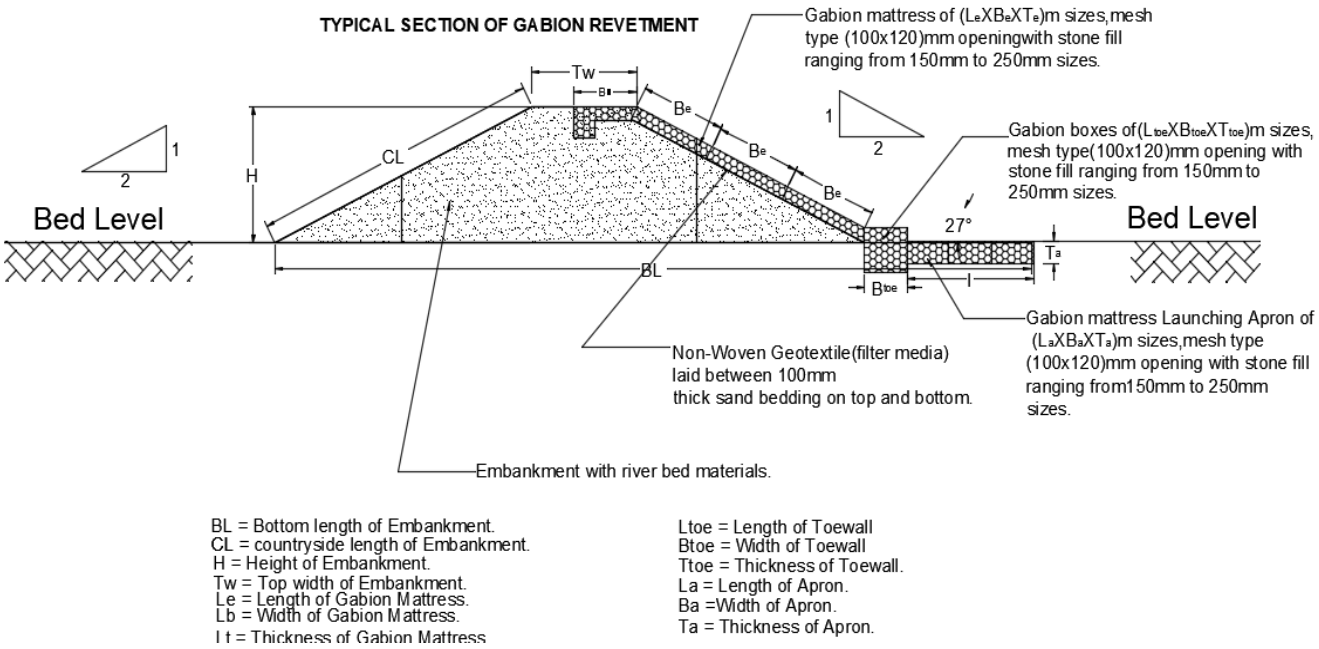

Figure 28: Typical cross section of a gabion revetment, FEMD, DES, MoWHS

Figure 29: Upstream of Changyul Bridge before construction of Gabion Revetment in 2014

Figure 30: Upstream of Changyul Bridge after construction of Gabion Revetment in 2014

Figure 31: Google image of Zomlingthang area

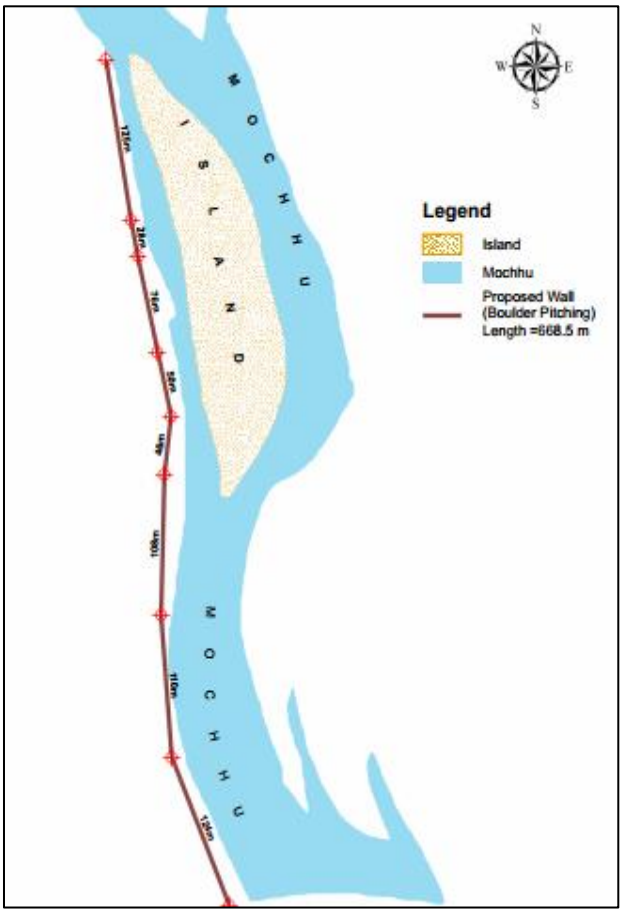

Figure 32: Location and length of the proposed riprap structure along right bank of Mochu at Zomlingthang

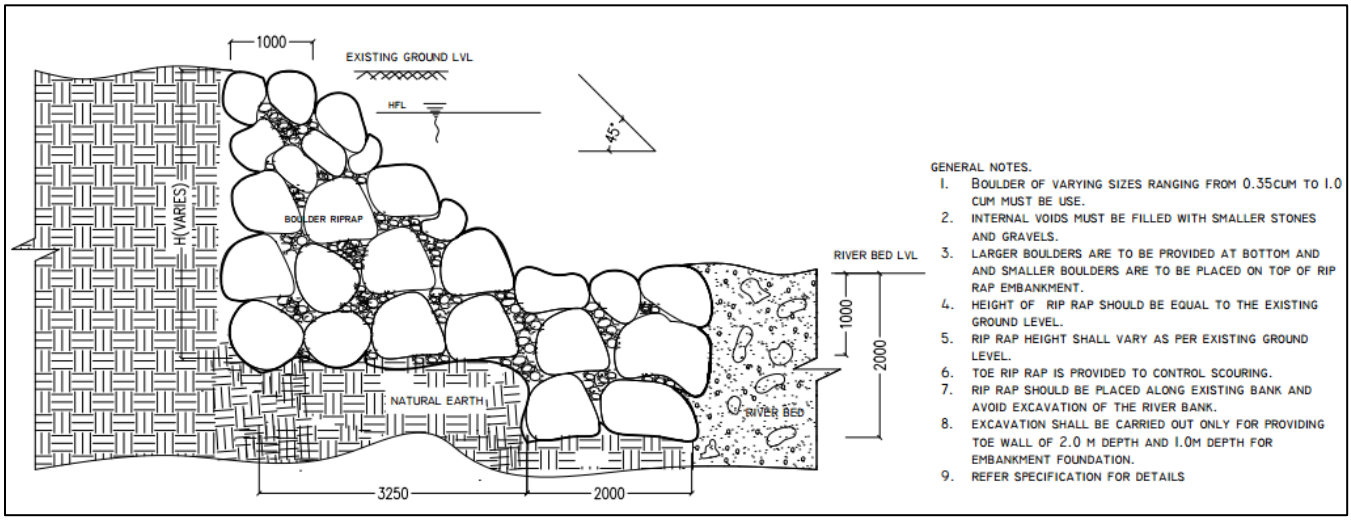

Figure 33: The proposed sectional view of designed Riprap structure at Zomlithang area

Limitations of the study

All meteorological and hydrological analysis has been performed on the basis of collected available observed data from NCHM. And if any error remains in the primary data collection of respective agency cannot be resolved within this study.

The purpose of the flood hazard maps produced in this study is only applicable for flood prone awareness programs and drafting the flood managing plans. It is not recommended for any sort administrative zonation purposes since other hazards have not been considered during the mapping.

References

1. Preliminary flood assessment of Punakha Dzongkhag, FEMD, DES, MoWHS
2. Flood inundation mapping using global datasets, Kuenzang Choden, 2017.
3. Punakha Dzongkhag website
4. National Statistics Bureau website
5. National Preliminary Flood Risk Assessment (PFRA), Ireland, Engineering Service, Office of Public Works.
6. Coursework book for Training in 'Flood Risk Assessment and Planning of Mitigation Measures' conducted by ADPC (Asian Disaster Preparedness Centre for FEMD staff and funded by UNDP- Climate Risk Management Project.
7. Flood control measures for effective flood management, FEMD, DES, MoHWS.