# CHAPTER-I
# INTRODUCTION

## 1.1 Background

A flood is relatively high stage of the river which is usually accompanied by overtopping of the banks of the river in a particular reach (Arora, 2006). The flood water consequently spreads over the flood plains. It causes damage to the crops and property, a lot of inconvenience to the people and sometimes loss of life also. The flood control is, therefore, required to reduce the flood damage. A complete flood control is, however, not feasible economically. While planning the river training works (flood control works) which reduce flood damages consistent with the cost involved should, therefore, be adopted.

Nepal, even being a small country having area 147,181 sq. km and mean width only 193 km has the elevation varies from 60 m to 8848 m belongs to 6,000 rivers with total length exceeding more than 45,000 km. Of these rivers, about 1,000 are more than 10 km long and approximately 100 are more than 160 km long (MoEST, 2007). This dense river channels when face the high summer monsoon precipitation followed by low pressure system around the continent invent the devastating flood events inundate and damage the land and infrastructures in its territory. Along with the highly concentrated monsoon precipitation, the other factors triggering flood hazards in Nepal are: high relief, steep mountain topography, and deep and narrow river valleys. Each year many people are killed and made homeless, and property and infrastructure are damaged by floods. As a result, the overall development of the country has been severely affected by repeated flooding. In the future, the global warming and resulting climate change phenomenon is likely to increase the frequency of flooding by increasing the intensity of extreme precipitation events and enhancing the melting of Glacier Lake. The encroachment of areas susceptible to floods to establish human settlements and to carry out infrastructural development in the recent past has increased the exposure of these areas to flood hazards and also being a least-developed, landlocked, and mountainous country with limited access to socioeconomic infrastructure and service facilities, vulnerability to flood disasters is likely to increase in the future. Inaccessibility, a low level of human development, and mass poverty are prominent reasons for the poor capacity to anticipate, cope with, resist, and recover from and adapt to different types of hazards, floods being among them. In addition, a high population growth rate, among other factors, has led to increasing poverty. As a result, vulnerability to flood hazards is likely to increase unless effective flood mitigation and management activities are implemented.

## 1.2 Rationale of the Study

The study has been carried out in the Marine River which lies in Sindhuli district located in the Central Development Region of Nepal. The present task of preparing dissertation in this topic for the Marine River is a research on how to protect the fertile valley, existing properties and inhabitants from the recurrent floods and their damaging effects in the study area.

Almost 98% of the Marine River basin lies in the hilly region which has fragile geology (DWIDP, 2009). The Marine river basin, in this study is situated in the high precipitation zone of Nepal. Flood in association with deforestation, hill slope cultivation and lack of soil conservation practices in the basin results in the prevalence of soil erosion and frequent landslides. Sediment carried by the Marine River is deposited once it enters the plain region. Further, its tributaries joining the river in the valley also contribute sediments. The combined effects of rising bed level and heavy rainfall in the monsoon season results the flow which cannot be contained in the natural cross section of the river. Consequently, the very fertile paddy fields lying on the both sides of the Marine River as well as settlement areas get inundated. It has resulted in a considerable loss of lives and properties in the past. High floods of 1899, 1985 and 1993 are some the examples of the flood events. Floods that occurred in the study area had swept away a couple of villages, killed a number of people and livestock and damaged agricultural land and standing crops, and other infrastructures in the past. Because of the ever increasing concentration of settlements, social and physical infrastructures in the flood prone areas, higher degree of flood related damages are likely to occur in the future. The impact of climate change may, further, aggravate the situation.

River training works are fundamental for flood management in relation to their adaptability to the different typologies of flood reaches, morphological conditions and hydraulic parameters. They can produce immediate benefits by removing or reducing the inundation and erosion problems. A detailed investigation of the existing river training works in the study area, implemented mostly by Department of Water

Induced Disaster Prevention (DWIDP, 2009), showed that the existing river training works are not found to be sufficient to protect the affected areas in almost all of the locations though they have been successful in acting as the mitigation measures in limited areas. Hence the preparation of a dissertation on river training with reference to food security including hydro-meteorological study in this river will ultimately guide for the implementation of river training works to have better socioeconomic future of the area.

## 1.3 Objectives of the Study

The main objective of this study is to carry out flood inundation analysis and recommend the river training works to be done in the Marine river catchments. The specific objectives of the study are:

- To asses the Hydro-meteorological situation.
- To identify the inundated areas resulting from floods of different return periods.
- To asses the benefit from the river training works in terms of food security.

## 1.4 Limitations of the Study

Since the model is used for the study, the major limitations of the study matches the limitations of the model parameters as generalized below.

- Three dimensional unsteady flow analyses are required to capture the actual flood phenomena. To simplify the calculation, one dimensional study flow analysis was done.
- Manning's 'n' are taken from the table fixed on the observed river morphology.
- Sediment effect is also significant in river analysis and also the HEC-RAS model has capability to include it but it needs the time series data of sediment. Due to the unavailability of these data sediment effects are neglected in this study.
- Food security implies the number of people there can be fed.
- Economic analysis has not done.

# CHAPTER-II
# LITERATURE REVIEW

## 2.1 General

Although hydrological and hydraulic science started well before the 15th century, it advanced more rapidly only in the 19th century. It was during this period when most important theories that form the backbone of this science were developed. To mention a few, the theory of capillary flow by the Hagen-Poiseuille equation; the law of porous media flow by Darcy; Fick's law of diffusion; and Manning's open-channel flow formula (Chow et al. 1988).

While the 19th century saw many theoretical approaches, the 20th century saw the development of empirical physics based approaches. Darcy's law combined with the continuity equation was applied for unsaturated flows. Richards Equation developed in 1931 was the first of its kind to present one-dimensional form for unsteady unsaturated flow in porous medium.

After the unit hydrograph method to transform effective rainfall to direct runoff and Hortonian overland flow was devised by Sherman in 1932, new doors opened in the field of open channel flow and stream flow analyses. A lot of work then started in the area of rainfall-runoff relationship. One of the breakthroughs was the development of SCS (Soil Conservation Service) method for computing abstractions from storm rainfall (SCS, 1972). The USLE (Universal Soil Loss Equation) for estimating gross erosion by water was developed and is by far the most widely used equation even today. Linsley and Crawford (1960) developed one of the earliest hydrologic simulation models widely known as the Stanford watershed model (Narula et. al. 2002).

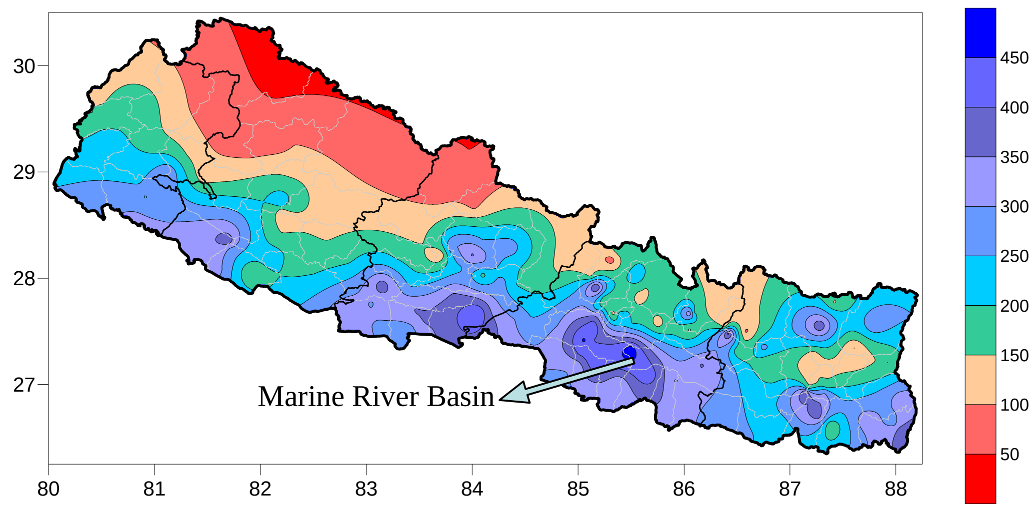
This chapter includes some important topic related to Hydrologic, Meteorological and Hydraulic sciences.

## 2.2 Rainfall

The term precipitation denotes all forms of water that reach the earth from the atmosphere. Precipitation may reach the surface of the earth in the form of drizzle, rain, snow, hail, sleets etc, The magnitude of precipitation varies with time and space. For precipitation to form :1)the atmosphere must have moisture, 2)there must be sufficient condensation nuclei present, 3) weather condition must be good for condensation of water vapour to take place, and 4) the product of condensation must reach the earth (Lal, 2003). The net precipitation a place and its form depend upon wind, temperature, humidity and pressure within the regions enclosing the cloud and the ground surface at the given place.

### 2.2.1 Extreme Rainfall

In Nepal, large amount of rainfall within a short period causes flash floods, massive landslides, soil erosion and sedimentation in hilly and mountainous regions and inundates the plain areas. The spatial distribution of highest 24 hours rainfall provides useful information of the flood and landslide prone zones. The extreme rainfall distribution is different from the annual or seasonal distribution. Siwalik and the Terai belt which generally receive less total seasonal rainfall received the highest 24 hour rainfall. Maximum and minimum 24 hour extreme rainfalls were found in Hariharpur gadi, Sindhuli (482.2mm) on 20 July 1993 (Practical Action, 2009). The highest extreme rainfall was mainly in the foothills of Mahabharat and Siwalik in central development region and in foothills of Siwalik in western development region. The **Figure 2-1** illustrates the 24 hour extreme rainfall in Nepal. Further it shows that the Sindhuli district as a whole lies in the region of highest 24 hour rainfall in Nepal. These regions are therefore prone to landslide, floods and inundation.




Source: Practical Action Nepal, 2009

**Figure 2-1: 24 hours highest rainfall (mm)**

### 2.2.2 Probable Maximum Precipitation

The greatest depth of rainfall that can occur in a given duration at a given location is known as the possible maximum or the probable maximum precipitation, abbreviated as PMP (DoED, 2009). It is the upper limit of the physically possible precipitation depth. It has been defined as that depth of precipitation which for a given area and duration can be reached but not exceeded under known meteorological conditions. If PMP for a given catchment is estimated than it can be used to provide an estimate of the probable flood. The PMF has virtually no risk of being exceeded. PMP values are generally not considered for the design of the engineering structures due to the reason it can not be economically feasible but it should be considered as an optimum reference.

### 2.2.3 Precipitation Climatology of Nepal

The distribution of precipitation has high value of spatial variation in Nepal. Nepal experiences the seasonal summer monsoon rainfall from June to September. Most of the days during June to September are cloudy and rainy. About 80% of the annual precipitation in the country falls between June and September under the influence of the summer monsoon circulation system (S. Marahatta and J.K. Bhusal, 2009). The amount of precipitation varies considerably from place to place because of the nonuniform rugged terrain. However the amount of summer monsoon rains generally declines from southeast to northwest.

The winter months December to February are relatively dry with clear skies. However, few spells of rain do occur during these months. In winter, major weather effective elements are the western disturbances so rain decreases in amount from northwest to both southward and eastward direction. The direction of predominating wind is Northwesterly during this season.

During March to May the country experiences pre-monsoon thundershower activities. The pre-monsoon rainfall activities are more frequent in the hilly regions than in the southern plains.

The period of October and November is considered as a post monsoon season and a transition from summer to winter. During October the country receives a few spells of post-monsoon thundershowers, similar in character to the pre-monsoon ones. The annual mean precipitation is around 1800 mm in Nepal. But owing to the great variation in the topography, it ranges from more than 5000mm along the southern slopes of the Annapurna range in the central Nepal to less than 250 mm in the north central portion near the Tibetan plateau. (Karki, 2009)

There are many reports about the study on precipitation in Nepal. With regard to rainfall Nepal is highly dominated by summer monsoon and its circulation arising from Bay of Bengal. It is estimated that the summer monsoon accounts for 80% of the annual rainfall in Nepal. According to Pokharel (2003), summer precipitation is high over middle mountains i.e. Mahabharat range; and decreased slightly over and decreased rapidly over Himalayan range.

In recent study, Barros et al. (2000) and Lang and Barros (2002) have noted significant spatial variability in precipitation in central Nepal (factor of differences over10km distance), but it did not show any specific dependence on elevation, particularly at the seasonal scale.

Studies by Barros et al. (2000); Shrestha (2000); and (Lang and Barros 2002) have shown that large rainfall amounts, on the order of 300-400/year, can fall along the south facing slopes of the Himalayas. Practical Action (2009) has shown that the overall rainfall trend in monsoon season is increasing in eastern, central, western and far western development region reaching upto 30 mm/year.

Studies also have shown that the climatology of Himalayan rainfall variability differs markedly from the rest of the Indian subcontinent (Shrestha et al. 2000). Shrestha et al. 2000 have also analysed the precipitation trend in Nepal and did not find any significant trend in annual and seasonal precipitation. But a study (Shrestha, 2004) conducted in Central Nepal clearly indicates the significant increase in extreme rainfall event in the recent decade (1991-2000) by three fold compared to 1971-1980 decade. GCM estimate shows the total precipitation in June, July and August will increase with 9.1% by 2030AD (OECD, 2003). Similarly, other model based projections have also shown the rising trend in annual precipitation over Nepal.

Similarly IPCC (2007) has shown that the frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increase of atmospheric water vapour.

Though there are various studies on the precipitation pattern over Nepal, there is very little study on the intensity of precipitation due to lack of data. PCJ (1996) has derived a formula for rainfall design intensity on the basis of available observed maximum rainfall intensity. The values obtained from this method shows that the intensity is high in the Mahabharat range, slightly decreases towards the Terai region and rapidly decreasing toward the Himalayan region. In case of river training analysis the rainfall and its intensity are the major factor to be studied for the design flow estimation. Hence this study is also focused on rainfall analysis and the analysis of frequency of the 24 hour maximum rainfall.

## 2.3 Flood

The portion of precipitation which appears in the surface streams of either perennial or intermittent nature is called the runoff. This is the flow collected from a drainage basin and appearing in an outlet of the basin. In a general sense it is the precipitation excess after meeting the evapotranspiration and deep percolation demands. Such excess amount of precipitation may cause the flood in the river. A flood may be defined as an overflow coming out from river. Whenever the water overflows the banks of the river, the river is said to be flooded. It is the temporary covering by water on land.

Flood and flood-induced inundation are stochastic phenomena occurring in nature, often influenced by anthropogenic actions. The causes of river flood are: rainfall, snow and ice melt, ice jams, landslides, failure of control works. Similarly, the flood from a drainage basin is influenced by various factors such as type of precipitation, intensity of rainfall, duration of rainfall, area distribution of rainfall, direction of storm movement, physiographic factors like land use, type of soil, area of basin, shape of the basin, elevation, slope, type of drainage network etc (Reddy, 2006). Though it is easy to identify the various factors which affect the flow in the river, it is rather difficult to quantify some of them and still more difficult to express maximum or average flow in terms of above factors.

The term 'River Flood' is used in a broader sense to cover several river activities that cause damage by means of inundating floodplains and adjacent terraces, bank cutting, river channel shifting, debris torrents during normally high discharges. Flash Floods are events with very little time occurring between the start of the flood and the peak discharge. It is an established fact over the years that flashfloods are of localized nature originating from intense rainfall due to cloudbursts, thunderstorms, and dam-breaks (Chow, 1959).

The effect of river flood is also termed as flood hazards as they cause harm to lives and economy of the area and country or the region in the larger extent.

Flooding is a serious issue for society and nation as a whole today. The incidence of floods worldwide has increased two-fold in the last 50 years and climate change scenarios suggest that the problem will continue to increase significantly (IPCC, 2007). River flooding is responsible for one-third of economic losses and over 40% of fatalities due to natural hazards worldwide. (DoED, 2009)

### 2.3.1 Estimation of Floods in Nepal

There are several empirical formulae for the estimation of flood flows. Empirical formulae have limited regional application. Many of them do not provide information on the probable return period; hence they shall be used only when a more accurate method cannot be applied because of lack of data. Some of the empirical formulae suitable for the flood prediction in ungauged basins of Nepal are reviewed here but these shall be used with great caution and proper justification.

In the absence of maximum instantaneous flow data at the proposed site regional methods such as DHM, WECS/DHM and PCJ method can be used, which are derived for ungauged locations of Nepal.

DHM method has been derived using the hydrometric data up to 1995 and hence can be considered an updated version of WECS Method. The following relationship has been used for computing the flood discharge by this method.

WECS/DHM is extensively used for flood prediction in the ungauged locations of Nepal for small projects. The methodology of flood prediction by this method can be found in referenced literature (WECS & DHM, 1990).

Using PCJ 1996, maximum storm-floods of different return periods could be derived based on maximum hourly intensity. This regional method was developed for the prediction of design floods in the absence of stream flow data at the ungauged locations of Nepal. The maximum hourly intensity of different frequency has been derived from daily maximum for 142 rainfall stations of Nepal that have more than 20 years of consistent data. Rainfall stations in the basin and/or nearby (outside) should be selected from 142 analyzed stations so that maximum hourly rainfall intensity on the entire basin could be carried out.

There are many other empirical formulas which are used in Nepalese Catchments. Modified Dickens method is one of the methods widely used in Nepal and north India for the estimation of peak discharge. This formula includes area as only one parameter and constant CT depends on the return period and snow fed area (Subramanya, 1995).

### 2.3.2 Review on Flood Problems

Nepal is the part of the Ganges/Brahmaputra River Basin, which is one of the most disaster-prone regions in the world. The Terai region amounting to only 17% of the total area and river valleys in the mountainous region of the country regarded as the granary of Nepal is continuously suffering from flooding. The rivers in this area become wide and braided with wide spread damages to agricultural lands. The damages are further characterized by erosion of banks and deposition of infertile coarse material on the cultivated land. The channel capacity of the rivers in this regime is said to be decreasing due to increased sediment coming from increased erosion rate at upland, thus making these rivers unable to accommodate large floods; as a result the adjoining area suffers from inundation (MoEST, 2007).

Besides, natural factors, anthropogenic factors also trigger floods and disasters. Encroachment of floodplains, obstruction of natural flow of rivers and sheet flow, faulty drainage system and river training works also contribute to the increased flooding and disaster. In Terai, devastation due to flood is also increasing due to rapid increase in population and human activities. The flood plains are being increasingly crowded to meet ever-increasing demands of food and fiber, and consequently the flood problem is exacerbated. Similarly, many hydraulic structures (dams/barrage, and bunds) constructed in some places just a few kilometers downstream of Indo-Nepal boarder on the Indian side have also exacerbated the flood situation in the Terai of Nepal (Bhusal,2004).

The devastating floods and incessant rains affect Terai and valley region and cause extensive damage to standing crops, physical and social infrastructure, environment, people's lives and livelihood and weaken the capacity of rural poor. Many people who live along the flood plains are poor, and are frequently overwhelmed by floods and other life-threatening extremes of weather. Because of economic reason, the poor and disadvantaged people of the rural communities are forced to settle in the areas adjoining riversides, marginal and vulnerable areas and therefore are the victim of flood disaster every year. Although various flood management measures are introduced in many places to prevent the negative consequences of flood disaster, the challenges are still at the forefront. It is generally found that the national government, local administration and the government have been mostly reliant on reactive approach to disaster management focusing mostly on the relief operation. Although relief operation is essential for proper flood disaster management, this is not adequate in itself and thus there is a need of measures for preventing hazards turning into disaster. Moreover, under proactive approach of reducing disaster risk, it is necessary to reduce the vulnerability of the people through improved livelihood opportunities and capacity build up and thus increased resilience. For designing an effective and efficient framework of disaster management there is a need to understand the grassroots problems, the institutional set up, and the livelihood assets of the community including local knowledge in flood management. While many studies have been conducted for reducing the disaster risk in many river basins of Nepal, most of these studies have been lopsided with major emphasis on the structural measures and have failed to address the root cause of disasters. The Marine River is one of the major river tributary of Bagmati which supports and affects lives of several thousand populations in the Sindhuli district. There have been a few studies in the basin and even those studied are not comprehensive. The recent study has been done by DWIDP (2009) which aimed at investigating the flood disaster problem for finding the root causes and devising strategy to manage flood with community-based approach by targeting improvement in the resilience of the community within the broader framework of enhancing livelihood options and poverty alleviation. Some historical flood events are also identified in Marine river basin which has done a lot of devastation that has shown in **Table 2-1**.

**Table 2-1: Flood events and the damages in Marine River Basin**

| SN | Flood Events | Phenomena | Damages | Remarks |
|---|---|---|---|---|
| 1 | 1899 | Great flood in Marine River | 2 villages were swept away near the confluence with Bagmati, Pipalmadi, Jakhauli | |
| 2 | 1982 | High Flood | | |
| 3 | 1984 | • Cloudburst<br>• Instantaneous flood without any warning<br>• Debris flow, heavy erosion in the upper half and flood | • Four persons were swept away by flood: 2 people survived and 2 persons drowned<br>• A lot of fishes were killed<br>• 8 domestic animals killed<br>• Flood damage mostly in the upper half of the Marine River, mostly u/s of Deojor Khola | • Flood also from Simle Khola |
| 4 | 1985 | High flood | | |
| 5 | 1993 | | • Flood damage mostly in the lower half of Marine River | • Similar to 1984 but no debris flow |
| 6 | 1994 | | • Mostly damaged d/s of Deojor Khola | Similar to the flood of 1993 |
| 7 | 2002 | Minor flood | | |
| 8 | 2003 | Minor flood | | |

Source: DWIDP, 2009

In July 1993, Nepal experienced the worst natural disaster in record. Two days of torrential rainfall in central Nepal triggered disastrous landslides, and caused many debris flows and major flooding in main streams and the Terai plains. About 28,000 people in the mountain areas and 42,000 people in the lowlands were affected. About 160 people in the highlands and over 1000 people in the lowlands were killed due to the devastating flood and landslides in Bagmati, Kulekhani and Narayani basins.

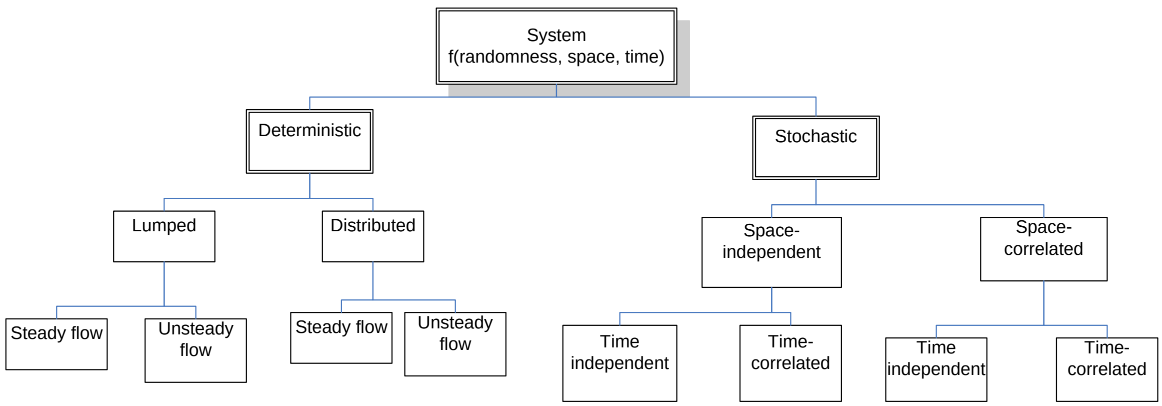
Infrastructures like Kulekhani hydroelectricity power plant, Bagmati barrage in the plains, roads, bridges, irrigation canals and check dams were severely damaged .The rainfall on 19th July 1993 at Tistung was recorded 540 mm with maximum intensity of 70 mm per hour and recurrence interval of less than 100 years. Such high intensity precipitation occurred over 530 sq km in the vicinity. On 20th July rainfall of 482.2 mm was recorded at Hariharpuri Garhi. About 500 to 800 sq km of the central portion of the Bagmati watershed received such high intensity precipitation ( DPTC, 1998).

## 2.4 Hydraulic Modeling

A hydraulic model is a mathematical simulation of complex hydraulic equations. Different types of models are used today for the different purpose of simulation. The choice of the model primarily depends upon the expected output with the input from existing databases, input variables, and the type of analysis required. Researchers and scientists have tried to simplify the simulation process using a systems approach represented by set of governing equations that support laws of physics. As a result a lot of approaches have been developed which convert the physical laws to abstract mathematical forms. These mathematical forms are described by a set of equations linking various variables that could behave randomly or could be functions of space and time thereby giving rise to stochastic and deterministic models.

### 2.4.1 Types of Hydraulic Modeling

A model involving random variables having a probability distribution is termed as stochastic model whereas a model with no random variables is called a deterministic model. Both stochastic and deterministic models are further classified into either conceptual or empirical, depending on whether the model is based on physical laws or not. Another common method of classification of models is as distributed or lumped. These describe how the model treats spatial variability. A lumped model takes no account of the spatial distribution of the input, whereas distributed models include spatial variability (Narula et al., 2002). Most runoff models used today are deterministic distributed models. The availability of GIS tools and more powerful computing facilities have led to the development of more advanced distributed models based on available information in both analog and digital form. Advances in the various fields such as water quality modeling, hydrochemical modeling, hydrogeological modeling have led to the development of different models at varying scales of application ranging from micro-watersheds to large river basins. The most important issues directly affecting the applicability of models include topography and terrain analysis and spatial distribution of inputs.




Source: Narula et al., 2002

**Figure 2-2: Hydraulic modeling types**

### 2.4.2 Calibration and validation of the model

Calibration and validation of model needs the observed long term data of gauge height and discharge. If the numerical calibration couldn't be done because of the unavailability of the data due to the absence of hydrological station in the basin the data obtained from field survey can be matched with the model simulated data and the result of the model can be checked whether it will be justified or not.

### 2.4.3 Application of the model in river training

While studying and working for the river training structures the use of model make it fast easy and efficient in following phases.

- Water depth assessment: The different depth of inundation can be identified.
- Floodplain delineation: The hydraulic model, HEC-RAS in association with GIS can generate the data of the width that the flood has extended.

- Inundation zonation: On the basis of inundation depth identified zonation can be done in GIS environment.
- Effect of levees on land reclamation**:** In the presence of levees, the area vulnerable to inundation for different return period flood can be identified and the socio-economically valuable areas can be reclaimed from the adverse effects of the river.

## 2.5 River Training Works

River Training is an age-old practice resulting in incessant development and application of human ingenuity to correct vagaries of the rivers. It requires deep and precise study of river mechanism and behaviour. River Training has assumed considerable significance in Nepal due to huge annual recurrence of the damage caused by floods. River Training in its broader aspects, cover all engineering works constructed on a river to guide and confine the flow to the river channel, and to control and regulate the river bed configuration for effective and safe movement of floods and river sediments. In essence, river training envisages training and stabilizing the river within a suitable waterway and along a certain alignment for a variety of proposes. River Training works involve large outlays and it is essential to select the type of the training work and material of construction so as to make optimum utilization of funds and effective and economical utilization of available construction material (MoEST, 2007).

Based on the purpose the river training works are classified as high water training, low Water Training and mean water training (R.K. Sharma and T.K. Sharma, 2002).

River Training aimed at a flood protection is called high water training or training for discharge. It envisages provision for adequate waterway for safe passage of maximum flood by proper location, alignment and height of the embankment for a given flood discharge without tending to change river conditions.

It is also termed as the training for depth. It envisages providing adequate water depths during low water periods in the river channel for navigation by concentrating flow in desired channels by closing other channels by the method of bandalling, i.e., contracting the width of the river channel with the help of groynes (Garg, 1998).

It is also termed as the training for sediment. It is by far the most important type of river training. It envisages the rectification of the river bed configuration and efficient movement of suspended and bed load for maintaining the channel in good condition. The maximum aggrading capacity of a stream occurs in the vicinity of mean water or dominant flood discharge, and as such tends to change the river bed in accordance with that stage of bed flow. Mean water training includes river training for efficient and exclusion from canals by correcting adverse river curvature to locate the canal offtake.

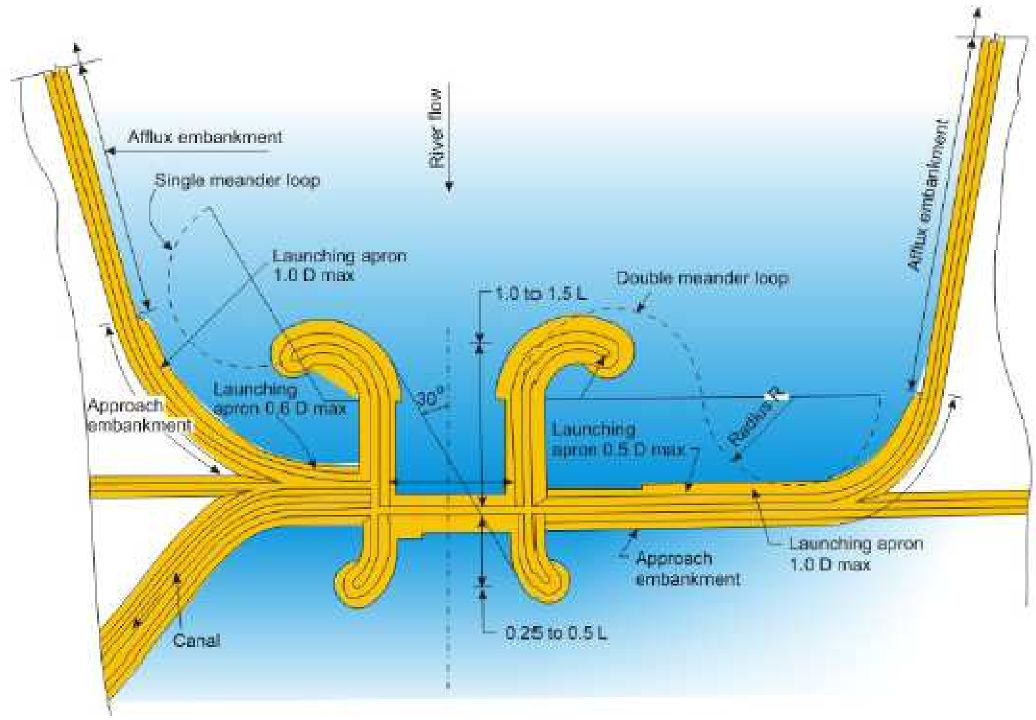
The flood mitigation measures have been considered both the non-structural as well as structural measures. Construction of different engineering structures is the part of structural measures while the watershed management and community development aspects represent the non-structural measures. This purpose of study includes only the Structural method of training hence reviewed.

Structural measures basically involve the use of engineering systems based on different technical practice, which in general need more investment. The following components are under the structural measures in order to reduce the adverse impacts of flood, inundation and river bank cutting (Garg, 1998):

- Embankment works (dikes) to prevent flood water and sediment from spreading over the land.
- Bank protection works (spur, revetments etc.) to protect the banks from erosion and accordingly to stabilize the river course; and

The bank protection works, especially the spurs are generally proposed in combination with the embankment works. The spur is necessary in order to guide high velocity flows and improve the conveyance of flow thereby reducing the erosion. Likewise, it also protects the revetment from scouring. The design of flood control measures are governed by the peak flood levels, which in turn depend on the scour and deposition of sediment. On the other hand, the characteristics of deposition and scour depend on depth of flow, flow velocity, degree of turbulence and eddies, the curvature of flow, slope angle and so on.

A typical layout of river training work is shown in **Figure 2-3** below.




(Source: CEIIT, 2009)

**Figure 2-3: Typical layout of river training work**

### 2.5.1 Flood Embankment

Levees are virtually earthen embankments usually constructed at suitable distance running parallel to the edge of riverbank. They may be constructed on one or both sides of river as required by the site conditions. They are extended and tied to high ground level available in the vicinity. The term dike and levee are also used as synonymous with embankment. (Garg, 1998)

The purpose of complete river training is to stabilize the channel along a certain alignment with a view to control the adverse effects of high-flood discharge, reduce bank erosion, avoid inundation, minimize the sedimentation of suspended loads, prevent the erosion of river bed and so forth. The primary objective of flood protection work by constructing levee is concerned with the confinement of the flood flow which is characterized by the level of river bank and other elements related to hydraulic characteristics such as gradient, depth, the width and bed material. By defining these parameters, it is possible to decide the nature of protection work.

### 2.5.2 Spurs

They are structures usually constructed on the riverbank normal to the dominant flow direction or at an angle pointing up stream or downstream. They may also be called Transverse Dykes, groynes or spur dikes also. They are constructed in order to protect the bank from which they are extended by deflecting the current away from the bank. A spur consists of shank and a nose or head. Shank is a bund of adequate section which connects the nose of the spur above the highest flood level on the river bank. The upstream face and nose of the spur are duly armoured with stone pitching and apron of proper dimensions (Modi, 1995).

### 2.5.3 Guide Banks

It is the protective or the training embankment constructed at the site of barrage, weir, bridge, etc to guide the river flow through the confined waterway without causing damage to the structure and its approaches. They are provided in the direction of flow. The guide banks are generally provided in pairs, symmetrical in plan and may either be parallel or converge slightly towards the structure and curved inlands on both ends to provide a bell mouth entry and smooth exit.

### 2.5.4 Bank Protection Works

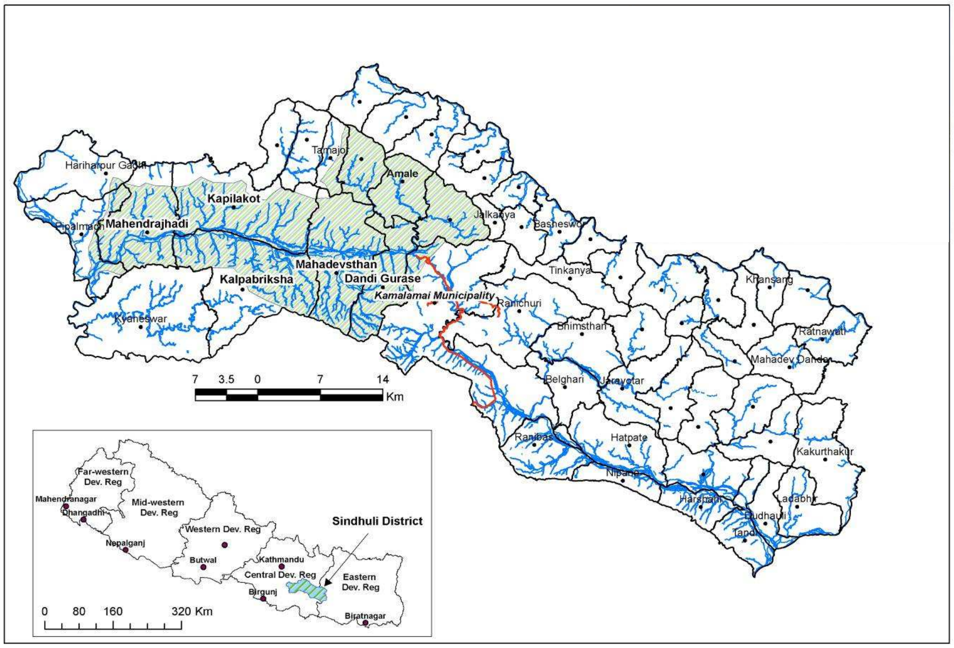
In river training works, protection of existing bank is the most important component. The purposes of the bank protection can be training of river, protection of adjacent agricultural land, protection of urban or villages areas, protection pf hydraulic structures, protection of flood embankment itself etc. Bank protection may be direct or indirect. Direct bank protection includes the work done on the bank itself, such as providing vegetal cover, pavement, revetment, grading of slopes etc. While the indirect bank protection works includes the works constructed not directly on the banks, but in front of them for reducing the erosive forces of the current either by deflecting the current away from the bank or by inducing silt deposition against them.

# CHAPTER-III
# STUDY AREA

## 3.1 General Features

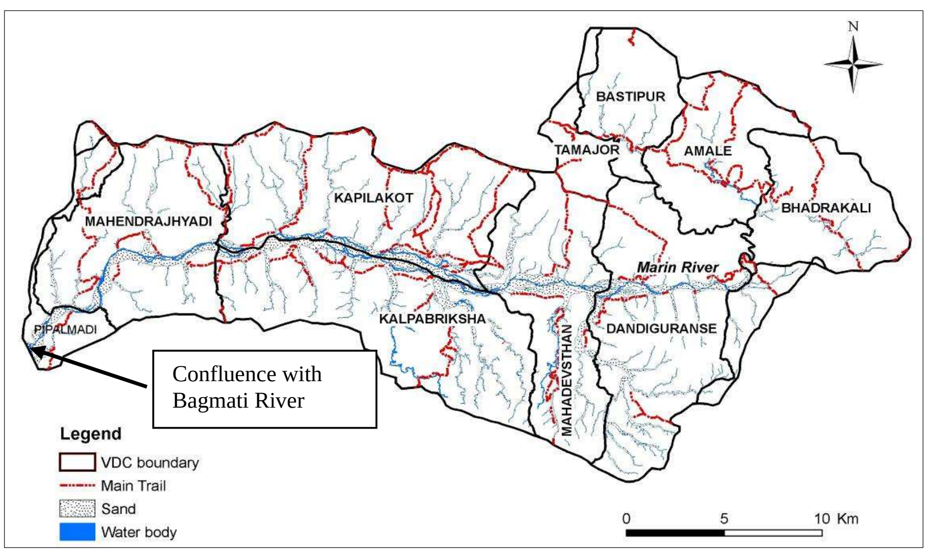
The Marine River lies in Sindhuli District which is located in the Central Development Region of Nepal. It is surrounded by Udayapur and Siraha districts in the East, Rautahat, Makawanpur and Kavrepalanchok in the West, Ramechap and Okhaldhunga in the North and Sarlahi, Mahottari and Dhanusha districts in the South. The map of Sindhuli district with the Marine River basin has been presented in **Figure 3-1.**

The Marine River is one of the major tributaries of the Bagmati River. The Marine River originates from Mahabharat hills and flows to the south east direction up to Dani village. It then changes its direction towards west until it joins the Bagmati River. The confluence of the Marine River with the Bagmati River lies near Shripur village of Pipalmadi Village Development Committee (VDC) of Sindhuli district. Geographically, it lies between 27$^{o}$ 17' 30" N to 27$^{o}$ 12' 30" N latitude and 85$^{o}$ 52' 30" E to 85$^{o}$ 30' 10" E longitude. Total river length is about 68 km and the basin area is about 544 km$^2$ (DWIDP, 2009). Since the flood related issues are of prime importance in the plain areas, this task will, therefore, be confined between its confluence with the Bagmati River and 45 km upstream of the confluence. The map of the study area of the Marine Basin has been presented in **Figure 3-2.** The villages and the Municipality that are in the study area and the part of the Marine River basin are also depicted in this map.




Source: DWIDP, 2009

**Figure 3-1: Map of Sindhuli district with the Marine River basin**




Source: DWIDP, 2009

**Figure 3-2: Marine River Basin**

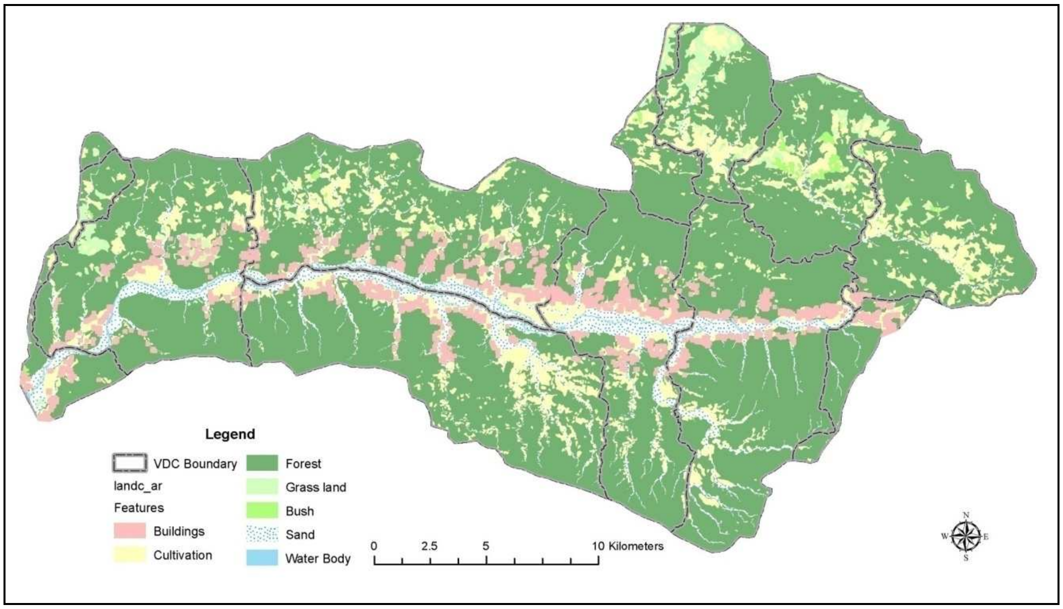
## 3.2 Climate

The climate of Marine river basin lies in subtropical zone. Although, there is not any hydro-meteorological station within the basin but in this study, the analysis of past rainfall data of the surrounding station shows that the 82% of rainfall occurs in monsoon season (June-September). This is also the region of high precipitation zone. Practical Action, 2009 has shown that the 24 hour extreme rainfall is highest around the Marine River Basin in Nepal. This study also has shown that the annual rainfall trend, pre monsoon trend, monsoon trend and post monsoon trend is also very high in this region comparing to other region in the country. This region is therefore prone to landslide, flash flood and inundation.

Past data analysis showed that the mean maximum temperature in Sindhuli District is $30^0$C, while the minimum is $14^0$C. Mean temperature pattern is also similar to the mean maximum and mean minimum temperature pattern. This varied above $20^0$C in Siwalik (Practical Action, 2009).

## 3.3 Topography

The Marine River Basin lies in the south-western part of the Sindhuli district. Its 544 $km^2$ basin area has the elevation ranges from 170 m (at the confluence with the Bagmati River) to 2,280 m at the origin (Department of Survey, 1995). Rectangular and barbed drainage patterns are common in the study area. The main tributaries of the Marine River are the Ghanghar Khola, the Maisuta Khola, the Phulbari Khola, and the Basan Khola. The river gradient of the streams that are higher at upper reaches of the watershed becomes gentle at the flat valley and flow into the ancient alluvial deposits. Such topographic characteristics may contribute to the delivery of sediment discharge to the Marine River. The catchment area comprises 98% mountainous area and the rest consists of flat land with an altitude of less than 200 m (DWIDP, 2009). The wide flat land spreads throughout the middle part of the watershed mainly from Dari to Jakhauli. These areas are well cultivated and densely populated. These features can be clearly seen in the land cover map given in **Figure 3-3**.




Source: DWIDP, 2009

**Figure 3-3: Land Cover Map of the Marine River Basin**

## 3.4 Geology

The Himalayan belt can be divided into the four tectonic zones from south to north (Gansser, 1964). These are Sub Himalaya or Siwaliks, Lesser Himalaya, Higher Himalaya and Tibetan-Tethys Himalaya. The study area covers parts of the lesser and the Sub Himalaya. The study area comprises of low to medium-grade metamorphic rocks of the Lesser Himalaya and sedimentary rocks of the Siwaliks. Main Boundary Thrust (MBT) is a longitudinal structure that sharply separates the terrigenic sedimentary rocks of the Sub Himalaya (Siwalik) from the low-grade meta-sedimentary rocks of the Upper Nuwakot Group of the Lesser Himalaya. The MBT dips 40-70 degree towards north. It is observed at the north of the confluences of the Marine River and Dhara Khola, and at the Simle Khola and Gunte Khola.

Likewise, Mahabharat Thrust does not appear as a clear-cut break as the MBT but rather as a narrow transitional zone displaying the reverse metamorphism (Stocklin and Bhattarai, 1980). The underlying low-grade metamorphic rocks (quartzites and phyllites) of Nawakot Complex rapidly pass upwards into the overlying high-grade metamorphic rocks (garnetiferous schist) of the Kathmandu Complex. The zone is characterized by coarse-grained garnetiferous schists that appear as cataclastic gneiss due to the intense shearing and mylonitization. This thrust was observed in Marine River and Gunte Khola.

The Marine River Fault is one of the major faults passing along the Marine River in nearly east-west direction. The gray mudstones of the Lower Siwaliks are thrust on the old terrace deposit. This thrust fault is also observed at Jutpani and in most of the tributaries of the Marine River that flow from north to south.

Besides the above mentioned formations, a few tributaries of Marine River originate from the Sindhuli Granite. The granites are coarse-grained and are made up of quartz, k-feldspar, muscovite, plagioclase, biotite and tourmaline. The area covered by granite is deeply weathered yielding Kaolin sole, sand, pebbles and boulders. Shallow debris avalanches and occasionally rockslides are common on the granites. Because of the chemical weathering at the intersections of joints, big boulders of granites are produced. Some bands of migmatite type gneiss and banded gneiss are commonly found in the Marine River sections.

The river terraces are topographic surface that mark former valley floor levels. Most of the terrace deposits close to the river valley are washed out by the flood. Some old alluvial terraced can be noticed all along the Marine River. They are distributed from the confluence of the Dari to Jakhauli in the Marine River basin.

During the high flood period, the streams occupy the entire valley and carry much of the debris as bed load material. After the water level is reduced, the valleys are filled with the debris. The streams channelize through the valley sediments and produces channel bars. This type of deposit is distributed throughout the valley from head to confluence of the Marine River. Likewise, the old alluvium is used as terraced cultivated land. During the flood event, such areas are washed out and the coarse material is deposited in the form of overbank deposit. This type of deposit can be observed from the confluence of the Dhanman Khola to downstream in the Marine River.

The streams are meandered at the lower reaches. The coarse alluvium is deposited on the convex side of the meanders and grows by individual increments outwards the meander curve. These are called point bar deposit can be observed at several locations along the Marine River. The major as well as few small tributaries have deposited sediments at the confluence with the main stream as alluvial fan deposits. The major alluvial fans deposited in the Marine River are by Ghangar Khola and Phulbari Khola. Other alluvial fans are deposited by the Dadi Khahare, Hathibanda Khahare, and at Boteni village.

The Marine River originates in the Lesser Himalaya, but the most part of it runs in the Siwaliks and joins the Bagmati River. The stream has a few major tributaries and many short tributaries and gullies extending up to the water divide. The Marine River is in its youth stage. The stream flows through different types of meta-sedimentary rocks of the Sub Himalaya. The rocks are moderately weathered and jointed, and development of strike valleys in them is common which were resulted due to the debris slide. Debris carried by the streams during the flood was deposited at the foothills. Therefore, the river valley comprises mostly cobble to boulder as the bed load material and consist of many flood plain deposits.

The Sindhuli Dun valley lies within the Siwalik Belt and are filled with thick pile of alluvial deposits composed of boulder, cobble, gravel, sand, silt and clay. The nearly east-west orientation of the Marine River valley offer large area of land for cultivation.

## 3.5 Flood Affected Areas

The flood affected areas identified are summarized in the **Table 3-1** below.

**Table 3-1: Areas affected by flood in the Marine River on both banks**

| Right Bank of Marine River | Left Bank of Marine River |
|---|---|
| Tamajor 6 | Bastipur 1, 2, 4 |
| Sirise, Panchmaiya | Salle, Sallephedi, Kerabari, Haitar |
| Bastipur 8,9 | Barajuthan, Chandanpur, Ratoguranse, Amale 6, 7, 8 |
| Rato Guranse | Simle, Patbans, Rajbans |
| Rajbas, Amale 9 | Bhadrakali 4 |
| Dandiguranse 2, 3, 5, 6 | Kusumtar |
| Dandi, Bhulbhule, Chaurahi, Swanra, Kharkhola | Kundule, Kamalamai 1 |
| Mahadevsthan 4, 5, 6, 8 | Chanaute, Dandi 9, 1, 7 |
| Deojor, Jayamangal, Barhabise, Mahesota | Majhenidamar, Dandi |
| Chhapbazar, Dhamile | Pandelejakhani, Mahadevsthan 2, 9 |
| Chandauli, Bhutaha, Gaduwa, Sakholi, Mungre | Badiman, Ghata, Baiteni |
| Banka, Sindure Dobhan | Kalpabrikshya 4, 6, 7 |
| Mahendrajhyadi 1, 2, 3, 4, 5 | Sahan, Chanaute, Matholi, Nakkale |
| Mankhanda, Jhyadi, Hatpara, Jutpani, Bhutre | Mahendrajhyadi 1, 4, 5 |
| Pipalmadi 1 | Boteni, Hattidamar, Chaichutte |
| Sirpurejhanjhane | Pipalmadi 9, Bafar |

Source : DADO, 2008

In view of the above data and based on the field observation, it can be said that the above mentioned locations are the vulnerable areas and are sensitive with respect to future impacts of flood events.

## 3.6 Inventory of Existing River Training Works

The existing river training measures have been implemented mostly by DWIDP. Similarly, isolated efforts of local government agencies like DDC and some non-governmental agencies have been found working in river training in the study area.

According to the local people, a co-ordinated effort to control all the affected areas are missing hence necessitating the preparation of Master Plan in this river for river training works.

Kans, a kind of grass, has been found useful for river bank protection. It helps in channelizing the flow in the main course of the river. No efforts were made to promote its use as a bio-engineering river training measure. However, when left undisturbed from local human encroachment through cattle grazing, they are found to be grown naturally and acting as an effective bio-engineering measure for bank protection.

**Table 3-2: Inventory of existing river training works in Marine River**

| S. No. | Location | Bank Side | Detail of Works | Agency* | Year (B. S.) | Status | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | Kusumtar, Dandiguranse VDC | Right | Gabion Spurs, 5 nos | DWIDP | 2055 | Working, stabilized and partially damaged | |
| 2 | Dandi, Dandiguranse VDC | Right | Gabioin Wall | DWIDP | 2060 | Working, partially damaged | |
| 3 | Dandi, Dandiguranse VDC | Right and Left | Gabion Wall & Gabion Retaining wall | DWIDP | 2062/63/64/65 | Working condition | After confluence of Jhor Khola |
| 4 | Dandi, Dandiguranse VDC | Left | Gabion Wall | DWIDP | 2062/63/64 | Working condition | Before confluence of Dandikhahare Khola |
| 5 | Chanaute, Dandiguranse VDC | Left | Gabion Wall | DWIDP | 2062/63 to 2063/64 | Working condition | Left side of Dandi Khahare |
| 6 | Chaurahi, Dandiguranse VDC | Right | Gabion Wall | DDC | 2061 | damaged and stabilized | |
| 7 | Swara, Dandiguranse VDC | Right | Gabion Wall & Gabion Spurs, 2 nos | DWIDP | 2062/63/64 | Partially damaged, working | |
| 8 | Majhidamar, Dandiguranse VDC | Left | Gabion Wall & Gabion Spurs, 3 nos | DDC | NA | Working condition | Confluence of Hathiban Khola |
| 9 | Waibatar, Mahadevsthan VDC | Left | Gabion Spur, 1 no | DDC | 2051 | Working, partially damaged | Confluence of Dhungajor Khola |
| 10 | Mahadevmadi, Mahadevsthan VDC | Right | Gabion Wall | DDC | NA | damaged and stabilized | After confluence of Deujor Khola |
| 11 | Ghat, Mahadevsthan VDC | Left | Gabion Spurs, 4 nos | DDC+SABIKA | 2052/53 & 2056 | Working condition | Confluence of Khanjani Khola |
| 12 | Bahrabise, Mahadevsthan VDC | Right | Spur, 1 nos & Gabion Wall | DWIDP | 2062 | Working condition | |
| 13 | Beteni, Kapilakot VDC | Left | Gabion Wall | DWIDP | 2064 | Working, partially damaged | |
| 14 | Mahesota, Kapilakot VDC | Right | Gabion Wall | NA | NA | Working condition | Right side of Mahesota Khola |
| 15 | Sahan, Kapilakot VDC | Left | Gabion Wall | DDC, DIO | 2051 & 2055 | now stabilized but not sufficient to protect the intended area | Confluence of Fulbari Khola |
| 16 | Boteni, Mahendrajhyadi VDC | Left | Gabion Spur, 1 no | DWIDP | 2064 | Working condition | After confluence of Boteni Khola |
| 17 | Simpur, Mahendrajhyadi VDC | Right | Gabion Spur, 1 no | MP Development Fund+DWIDP | 2057 & 2064 | Partially damaged, working | |
| 18 | Bakhaphar, Pipalmadi VDC | Left | Gabion Wall | DWIDP | 2063/64 | Working condition | |
| 19 | Bakhaphar, Pipalmadi VDC | Left | Gabion Spur, 1 no | DWIDP | 2064/65 | Working condition | |

* Public Participation included

*Acronyms :*

DWIDP : Department of Water Induced Disaster Prevention
DDC : District Development Committee
VDC : Village Development Committee
SABIKA : An NGO
DIO : District Irrigation Office
NA : Not Available

Source: DWIDP, 2009

## 3.7 Socioeconomic Condition of the Marine River Basin

The general socioeconomic conditions including identification of Population Distribution, flood affected areas, Land use pattern, agricultural practices and food security issues of the study area are reviewed below.

### 3.7.1 Population Distribution

The population distribution in the Marine River Basin is presented in **Table 3-3**. This shows that Kamalamai Municipality has the highest population followed by Kapilakot and Kalpabrishykha VDC and the lowest population lies in Amale VDC. However, only a small part of municipality area falls in Marine Basin.

**Table 3-4: Population distribution in Marine River Basin**

| S. No. | VDC/Municipality | Total Population |
|---|---|---|
| 1 | Amale | 2298 |
| 2 | Bastipur | 2909 |
| 3 | Bhadrakali | 4591 |
| 4 | Dadiguranshe | 4851 |
| 5 | Hariharpur Gadhi | 4005 |
| 6 | Kalpabrishykha | 8849 |
| 7 | Kamalamai | 32838 |
| 8 | Kapilakot | 10062 |
| 9 | Mahadevsthan | 6197 |
| 10 | Mahendrajhayadi | 5130 |
| 11 | Pipalmadi | 7487 |
| 12 | Tamajor | 2326 |

Source: Jilla Parshwa Chitra (District Profile), Sindhuli District, 2065

### 3.7.2 Agriculture Practices

Area of major crops cultivated in different flood affected VDCs have been given with their production in Table 2-4 which presents the agricultural area and production in the VDCs affected by the flood of the Marine River. These data present existing scenario of agriculture condition in the flood affected areas. The data in the following table shows that the there is huge agricultural area and production affected by the Marine River which is altimately related to the food security issue

**Table 3-5: Agricultural area and production affected by Marine River**

| VDCs | Crops | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rice | | Maize | | Wheat | | Millet | | Potato | |
| | Area (ha) | Yield (mt) | Area (ha) | Yield (mt) | Area (ha) | Yield (mt) | Area (ha) | Yield (mt) | Area (ha) | Yield (mt) |
| Dandiguranse | 270 | 783 | 450 | 995 | 114 | 279.3 | 215 | 220 | 22 | 186 |
| Kalpabrikshya | 480 | 1427.5 | 760 | 1732 | 164 | 401.8 | 400 | 600 | 22 | 188 |
| Kapilakot | 491 | 1458.9 | 440 | 1018 | 160 | 41201 | 115 | 18205 | 30 | 258 |
| Mahadevsthan | 340 | 1007 | 690 | 1508 | 105 | 275.35 | 236 | 252.5 | 40 | 330 |
| Mahendrajhyadi | 180 | 512 | 945 | 1419 | 64 | 150.8 | 202 | 303 | 25 | 180 |

Source: DADO, Sindhuli, 2007.

## CHAPTER-IV

## METHODOLOGY

**Figure 4.1** briefly describes the overall methodology adopted in this study. It also gives an overview of the various parameters that are involved in the analysis and computation. The detailed methods for the calculation and estimation of these parameters are further described in the sequent sections.

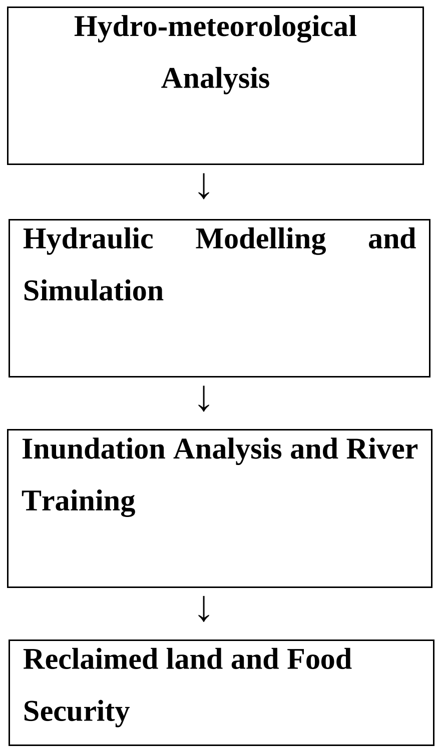



**Figure 4-1: Flowchart for the overall methodology of the study**

## 4.1 Rainfall Analysis

Rainfall is the precipitation of liquid water particles, either in the form of drops of more than 0.5 mm diameter or in the form of smaller widely scattered drops. The drops of rain are generally larger than those of drizzle. When the precipitation process is very active, the lower air is moist and the clouds are very deep than rainfall occers in the form of heavy downpours causing flash floods.

Rainfall is probably the first hydrological phenomenon to have been recorded by man. To consider rainfall as the input to the flood flow, the rainfall analysis is important in every basin. The Marine River is a major tributary of the Bagmati River. There are no raingauge stations in the Marine River Basin. Being close to the Marine River Basin, rainfall data of Hariharpurgadi and Sindhuligadi are considered as the representative of the basin.

The rainfall process is essentially random in nature. The rainfall obtained from a single rainfall station is known as the point rainfall or station rainfall. The daily rainfalls recorded at a station may be totaled to yield for longer period such as monthly rainfall seasonal rainfall and annual rainfall. If the observed rainfall in any year is less than the normal annual rainfall than it is called a deficit year or dry year and on the other way it is called a surplus year or wet year.

It is not possible to tabulate all the rainfall measurement, data- wise; therefore it is felt desirable to take the mean value of rainfall for the entire year. In this study the the bar diagram and frequency analysis have been applied for the analysis of rainfall.

### 4.1.1 Frequency Analysis

Frequency analysis is carried out using 24 hour maximum rainfall based on the data recorded at Hariharpurgadi using Gumbel Extreme Value Type I distribution. The 24 hour maximum rainfall for different return periods is than presented in table.

### Gumbel Extreme Value Type I

This Extreme Value Distribution was introduced by Gumbel (1914) and is commonly known as Gumbel's Distribution. It is one of the most widely used probability distribution functions for extreme values in Hydrological and Meteorological studies for the prediction of flood peaks, maximum rainfall, maximum wind speed, etc.

According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value of x0

$$P(X \geq x_0) = 1 - e^{-e^{-y}}$$

in which y is a dimensionless variable given by

$$y = \alpha(x - a)$$
$$a = \bar{x} - 0.45005\sigma_x$$

Thus

$$y = \frac{1.2825(x - \bar{x})}{\sigma_x} + 0.577$$

where $\bar{x}$ = mean and $\sigma_x$ = standard deviation of the variant X. In practice it is the value of X for a given P that is required and the eqn. is transposed as

$$Y_p = -\ln[-\ln(1 - P)]$$

Noting that return period T=1/P and designating YT= the value of y, commonly called the reduced variant, for a given T,

$$Y_T = -\left[\ln\ln\frac{T}{T-1}\right]$$
$$Y_T = -\left[0.834 + 2.303\log\log\frac{T}{T-1}\right]$$

So, the value of variant X with a return period T is

$$x_T = \bar{x} + K\sigma_x$$
$$where,\ K = \frac{(y_T - \overline{y_n})}{\sigma_x}$$

$\overline{y_n}$ =mean of reduced variant

## 4.2 Discharge Computation

There is no flow gauging station in the Marine River. DHM (1998) estimated the monthly mean runoffs from the watershed area by using the regression relationship (discharge verses basin area) which is used for the analysis of flow. The monthly discharge of the Marine River is estimated near the Bhabar is presented in the result.

As the Marine River is an un-gauged river, the regional and empirical methods have been adopted in estimating the flood magnitudes. The methods adopted for estimating the high flow analysis for the study of the Marine River are Water and Energy Commission Secretariat (WECS) Approach, Modified Dickens Method and DHM Method. The flood estimation at various locations for different return periods (2, 5, 10, 15, 20, 25, 50, 100 and 200 years) has been calculated. The estimation of flood by using above methods is presented below **Table 5-3.**

### 4.2.1 Water and Energy Commission Secretariat (WECS) Method

Water and Energy Commission has published a regional hydrological analysis report in which the flood flow in any river of catchment area below 3000 m of elevation is given by

$$Q_2 = 1.8767\ (A+1)\ 0.8783$$

$$Q_{100} = 14.63\ (A+1)\ 0.7342$$

Where, suffix $_2$ and $_{100}$ stands for the return period in numbers of years. The flood flows for any other return period T is then given by:

$$Q_T = exp\ (ln\ Q2 + S\alpha)$$

Where, S is the standard deviation of natural logarithms of annual floods and $\alpha$ stands for a standardized normal variant for particular return period T. S can be calculated as,

$$S = ln\ (Q_{100}/\ Q_2)\ /2.326$$

### 4.2.2 Modified Dicken's Method

This is one of the methods widely used in Nepal and north India for the estimation of peak discharge. The peak discharge can be calculated by using the following formula:

$$Q_T = C_T\ A\ 3/4$$

Where $C_T$ is for the return period T is given by

$$C_T = 2.342\ log\ (0.6T)\ log\ (1185/P) + 4$$

With $P = 100(As+ 6)/A$

'As' is the snow covered area out of total Catchment area A.

Here, $As= 0$ and P is defined as $P= 600/A$.

### 4.2.3 DHM Method

This method has been derived using the hydrometric data up to 1995 and hence can be considered an updated version of WECS Method. The following relationship has been used for computing the flood discharge by this method:

$Q_2 = 2.29(A3000)0.86$

$Q_{100} = 20.7(A3000)0.72$

The flows for any other return period 'T" is then given by:

$Q_T = exp\ (1n\ Q_2 + S\ \sigma)$

Where,

$S \quad = \quad ln\ (Q_{100} / Q_2\ ) / 2.326$

$\sigma$ = Standard Normal Variate

The values of standard normal variate required for flood estimation for WECS's method and DHM method are given in

**Table 4-1 Values for Standard Normal Variate for various return periods**

| Return Period (T) years | Standard Normal Variate (S) |
|---|---|
| 2 | 0 |
| 5 | 0.84 |
| 10 | 1.28 |
| 15 | 1.37 |
| 20 | 1.65 |
| 25 | 1.67 |
| 50 | 2.05 |
| 100 | 2.33 |
| 200 | 2.84 |

## 4.3 Hydraulic Computation

The flood hazard assessment in the Marine River basin has been carried out using Hydrologic Engineering Centre's River Analysis System (HEC-RAS). The use of this application gives the water surface elevation of flood discharge for the different return periods thereby providing the information on the area of inundation (USACE, 2002). Thus the flood prone areas can be assessed to flood of particular return period. The flow has been considered as a steady and gradually varying flow.

### 4.3.1 Theoretical Background of HEC-RAS

Hydrologic Engineering Center's River Analysis System (HEC-RAS) was developed by the US Army Crops of Engineers to perform 1D analysis of steady flow water surface profile, unsteady flow simulation, movable boundary sediment transport computation and water quality analysis. HEC- RAS is applied in the current study as a part of hydrodynamic model. Steady flow case is only followed by this study as explained below.

Water surface profiles for steady flow are computed from one section to the next by using energy equation for sections 1 and 2. **(Figure 4.2)**

$$Z_2 + y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$ (USACE, 2002)

Where Z1, Z2 : Datum head at sections1 and 2

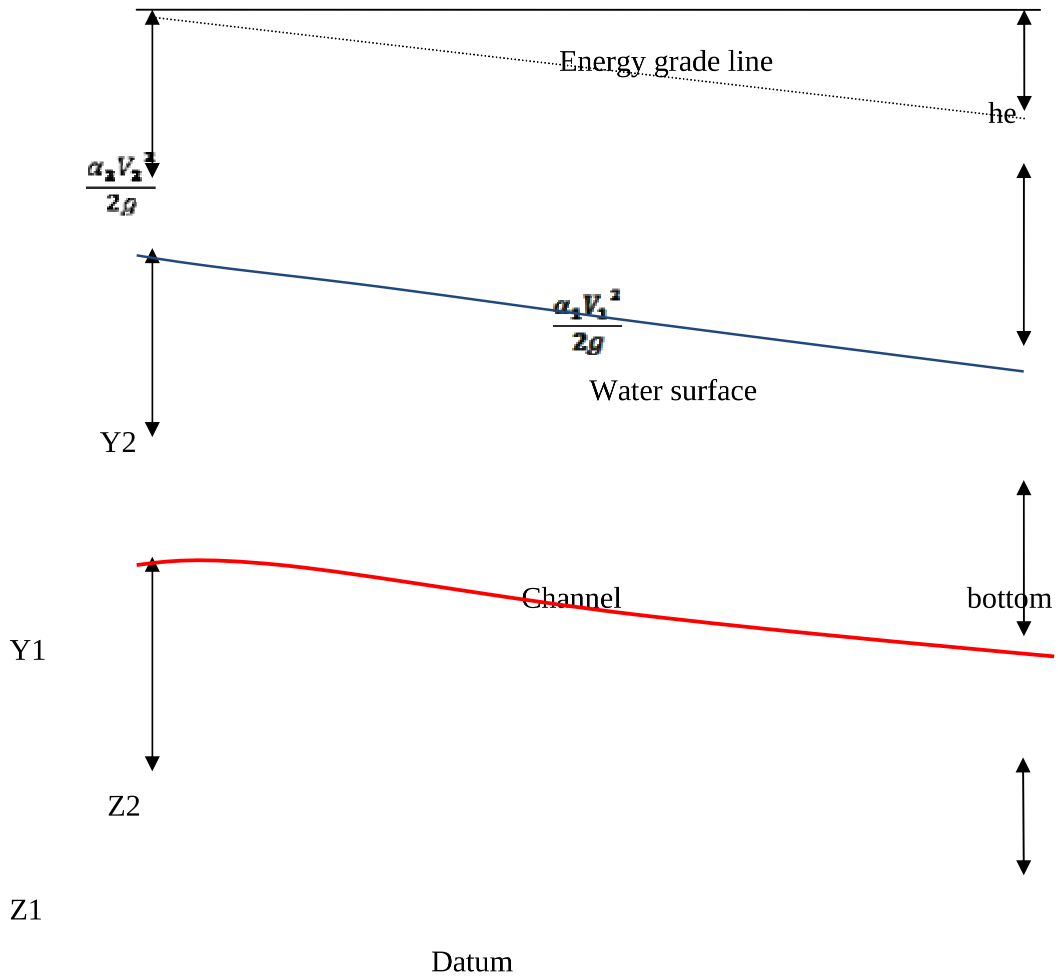
y1, y2 : water depth at sections1 and 2

v1, v2: velocities at sections1 and 2

he = Energy Head loss

$\alpha_1, \alpha_2$ = Velocity weighting coefficients

g = gravitational acceleration




Source : USACE, 2002

**Figure 4-2: Energy heads**

## Energy head loss

The energy head loss between two sections is comprised of frictional loss and eddy loss (contraction or expansion loss). The energy head loss ($h_e$) is given by

$$h_e = h_f + h_c \qquad \text{(USACE, 2002)}$$

where $h_f$ = friction loss

$h_c$ = eddy loss

$$h_e = L\bar{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

Where L = Discharge weighted reach length

$\bar{S}_f$ = Representative friction slope between two sections

C = contraction or expansion loss coefficient

The discharge weighted reach length is given by

$$L = \frac{L_{lob}\,\overline{Q_{lob}} + L_{ch}\,\overline{Q_{ch}} + L_{rob}\,\overline{Q_{rob}}}{\overline{Q_{lob}} + \overline{Q_{ch}} + \overline{Q_{rob}}}$$ (USACE, 2002)

Where $\overline{Q_{lob}}$ , $\overline{Q_{ch}}$ , $\overline{Q_{rob}}$ = average flow in left, main channel and right overbank

$L_{lob}$, $L_{ch}$, $L_{rob}$ = cross-section length in left, main channel and right overbank

Conveyance (K) is computed by

$$K = \frac{AR^{\frac{2}{3}}}{n}$$ (USACE, 2002)

Where n = Roughness coefficient

A = Cross-sectional area

R = Hydraulic radius = A/P where P = wetted perimeter

The cross-section is subdivided and K is computed for each sub-division, and total K is found.

Friction slope is computed using Manning's equation:

$$S_f = \left(\frac{Q}{K}\right)^2$$ (USACE, 2002)

Representative friction slope between two sections is computed by different methods, such as taking arithmetic mean, geometric mean or harmonic mean.

$$\overline{S_f} = \left(\frac{Q1 + Q2}{K1 + K2}\right)^2$$ (USACE, 2002)

Alternatively, $\overline{S_f}$ can also be computed by different methods such as taking arithmetic mean, geometric mean or harmonic mean.

## Computation procedure

- Assume a water surface elevation at the upstream cross-section (or downstream cross-section is the supercritical flow profile is computed).
- Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity heads.
- Compute L, $\overline{S_f}$ and $h_e$.
- Compute water surface profile by using energy equation (WS2).
- Compare the computed value (WS2) with assumed value and repeat above steps until the value agrees to 0.003m, or the user defined tolerance.

## HEC-RAS simplifications of St. Venant equation

Assuming horizontal water surface at each cross-section normal to the direction of flow and neglecting exchange of momentum between channel and flood plain, the discharge is distributed according to conveyance, .i.e.

$$Q_c = \varphi Q$$

Where $Q_c$ =flow in channel

Q = total flow

$$\varphi = \frac{K_c}{K_c + K_f}$$

Where $K_c$ = conveyance in channel

$K_f$ = conveyance in flood plain

With these assumptions, 1D equation of motion adopted for HEC-RAS is

$$\frac{\partial A}{\partial t} + \frac{\partial(\varphi Q)}{\partial x_c} + \frac{\partial[(1-\varphi)Q]}{\partial x_f} = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\frac{\varphi^2 Q^2}{A_c}\right)}{\partial x_c} + \frac{\partial\left(\frac{(1-[\varphi)]^2 Q^2}{A_f}\right)}{\partial x_f} + gA_c\left(\frac{\partial Z}{\partial x_c} + S_{fc}\right) + gA_f\left(\frac{\partial Z}{\partial x_f} + S_{ff}\right) = 0$$

(USACE, 2002)

Subscript c and f refer to channel and flood plain respectively.

Where Z = water surface elevation

### Solution of these equations

These equations are approximated using implicit finite difference schemes, and solved numerically using Newton-Raphson iteration procedure.

### Boundary Conditions

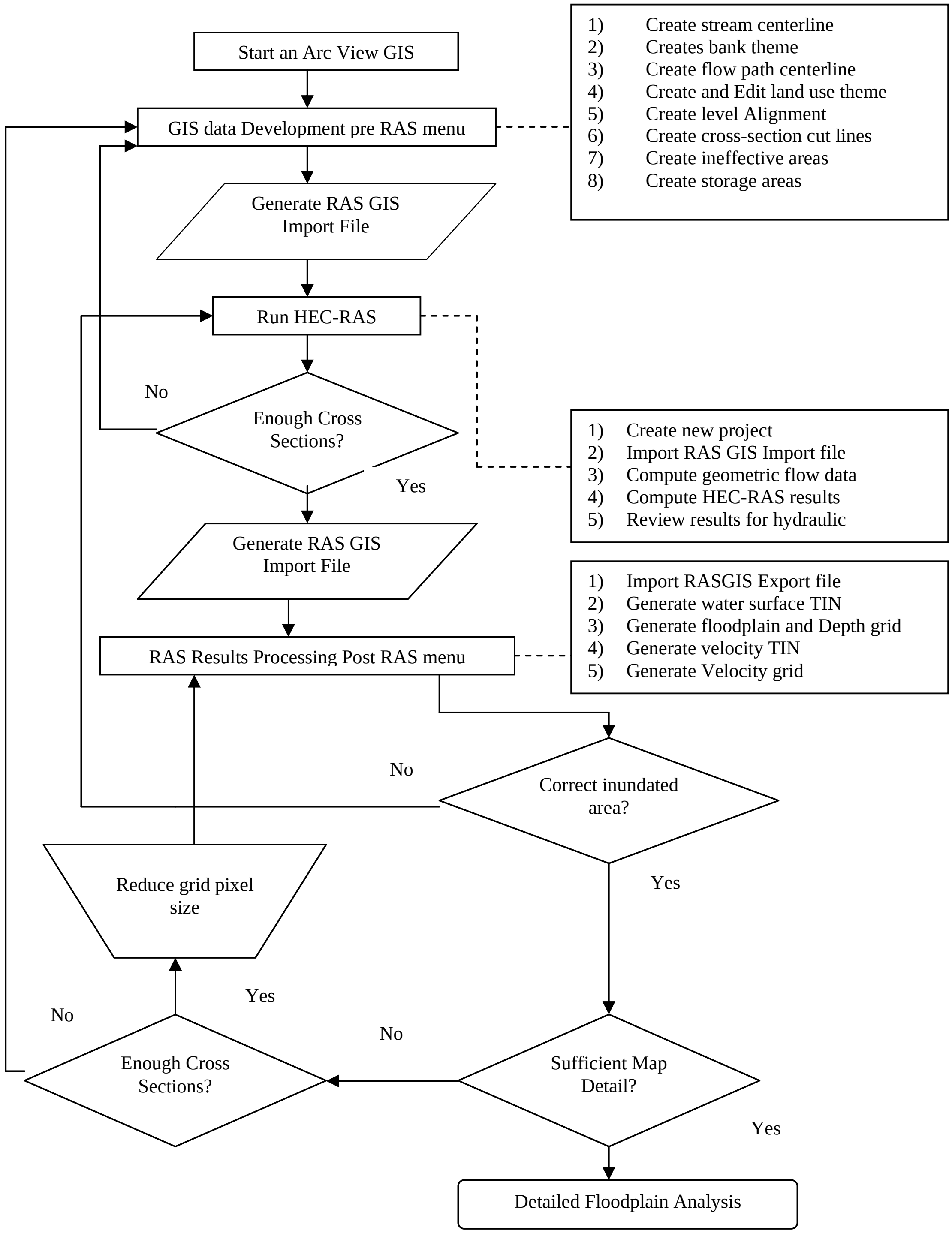
For a reach of a river, there are N computational nodes which bound N-1 finite difference cells. From these cells 2N-2 finite difference equations can be developed. Because there are 2N unknowns, 2 additional equations are required. These equations are provided by boundary conditions for each reach.

- For subcritical flow, both upstream and downstream boundary conditions are required.
- For supercritical flow, only downstream boundary condition is required.

### Interior Boundary Conditions

A network is composed of a set of M individual reaches. Interior boundary conditions are required to specify connection between reaches. Depending on type of reach junction, one of two equations, either continuity of flow or continuity of stage, is applied.

The general approach used in HEC-RAS model is depicted in **Figure 4-3** below.




Source: USACE, 2002

**Figure 4-3: HEC-RAS modeling approach**

The major steps are as explained below:

HEC-GeoRAS is applied to create an import file of geometric attribute data for use in HEC-RAS and to view water surface profile data exported from RAS. The graphical user interface allows users with minimal GIS experience to create a HEC-RAS import file containing geometric attribute data from an existing digital terrain model.

The pre-RAS application of HEC GeoRAS is used to prepare HEC-RAS input data file. The following data sets are prepared in the ArcView GeoRAS environment so as to export the geometric data file to the HEC-RAS model.

- TIN model as DEM input
- River Banks
- Flow path
- Centerline of river
- Cross-section cut lines

The pre-RAS operation is carried out in the order and sequence and then exported geometry file created to export to HEC-RAS model. Discharge is taken as upstream boundary, whereas rating curve is taken as downstream boundary. Set up of HEC-RAS model is than done and generation of several scenarios of flood inundation is carried out. With increasing magnitudes of discharge or stage at the upstream, the flood inundation scenarios are generated by running HEC-RAS model.

### 4.3.2 Development of the Model

Development of the model includes the followings.

i) Preparation of data
ii) Assigning values to model parameters
iii) Setting and Execution of the model

### i. Preparation of data

HEC-RAS model requires two types of data: domain data and flow data. The design flood data obtained by Modified Dickens is used as flow data while domain data are obtained as given below.

### Domain data (Geometric Data)

The Domain or the geometric data required for the model set up includes the river cross sections and the river network data. In addition to these data, levee data is also needed to assess its impact on flood in river and to be constructed as a river training structure. This geometric data was prepared from Triangulated Irregular Network (TIN) in HEC-GeoRAS. The topographical data obtained from the river X-section as well as other spot elevations (random points) within the river channel and flood plain areas in the river valley was obtained from the field survey (DWIDP, 2009). In addition, the topographical digital data (scale 1:25,000) of the Department of Survey has also been used while preparing the TIN. Based on the digital topographical maps and recent satellite image, the river center line as well as river banks of the Marine River were digitized in GIS. Also, the existing levees along with proposed structures were also added to the model at necessary locations assigning the dimension (length and height) as a Pre-RAS process.

The study area was divided into 10 reaches on the basis of magnitude of flow contributed from its tributaries for the purpose of hydraulic modeling using HEC-RAS. **Figure 3-4** given below illustrates the plan of the river model. The Reach 1 is fixed near Kukurdaha Village. The Reach 2 is fixed d/s of Khanjani Khola confluence. Reach 3 is fixed d/s of Maheshwota Khola confluence while the Reach 4 is fixed d/s of Phulbari Khola confluence. The Reach 5, Reach 6, Reach 7, Reach 8 and Reach 9 are located at the confluences d/s of Telani Khola, d/s of Maruwa Khola, d/s of Mungre Khola, d/s of Lakura Khola, d/s of Basan Khola and finnaly the Reach 10 is fixed near Shripur village.

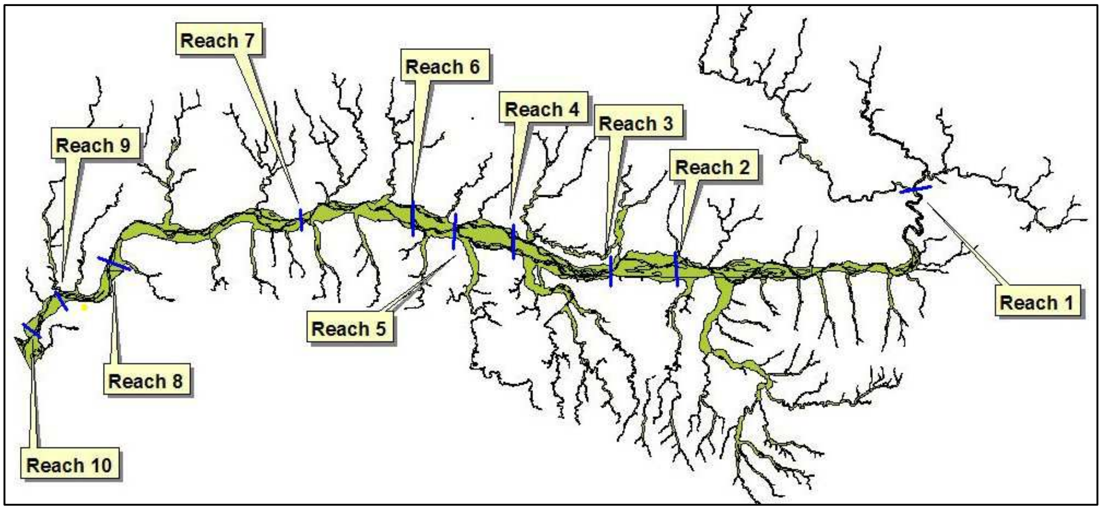



**Figure 4-4: Plan view of the river model**

## Flow Data

Using the mentioned discharge computation methods in section 3.2 above, the discharge of the rivers for various return periods have been calculated and presented in table for the comparison. The discharge calculated by the modified Dickens Method is employed for design flood. The river training structures are generally designed for the flood of 50 years but it is the fact that the life time of the gabion wire used for the flood embankment doesn't exceed more than 25 years and in normal condition its minimum life time is approximately 15 year (DWIDP, 2009). That is why both 25 and 15 year floods are taken into consideration to make analysis for different scenarios for academic and practical purposes both. Department of Water Induced Disaster Prevention (DWIDP) has already done the study taking 50 years design flood obtained by Modified Dickens method hence it is assumed as reference and a high flood of 100 years return period is also considered. The Discharge values obtained by Modified Dickens method are used for the hydraulic computation. In order to account the flow coming from the tributaries, the river section falling in the study area was divided into 10 reaches. It is shown in **Figure 4-4.**

### ii. Model Parameters

In case of unavailability of discharge and channel cross-section data, Manning's n value is obtained from Standard Table. The values of the Manning's coefficient (n) for the river side over bank were assumed depending upon the nature of the surface (Chow, 1959). The table is given in **Annex I**. The values of n used for the hydraulic model was validated using the available literature and also based on the field survey carried out by DWIDP (2009). The expansion and contraction coefficients used for the river stations are 0.3 and 0.1 respectively taking Chow (1959) as reference.

### iii. Setting and Execution of the Model for Flood Inundation Mapping

The results obtained from the HEC-RAS model run are imported to the Arc View GIS environment using Post Geo-RAS menus. The Post Geo-RAS operation calculates the delineation of flood plain boundary taking into account the water depth. The model using the water surface profile data from HEC-RAS and converting it to DEM of water depth calculates the water depth of river and its resided floodplain.

### Scenarios

The model developed for the Marine River was executed for flows of three different return periods: 15 yr, 25 yr and 100 yr. The position and depth of levees as a river training tool were then fixed. The effect of levees in land reclamation was analyzed for these three cases. The model results for 50 yr return period (DWIDP, 2009) have been referred to for the estimation of different parameters required in the model.

## 3.5 Food Security

The resulting reclaimed agricultural land can be ultimately correlated to its economic value with respect to the production of crops. The cropping pattern in the Nepalese context is to farm three different cereal crops, i.e. rice, wheat and maize annually. Plantation of rice for two seasons is possible along with a single season of wheat in the floodplain area. Therefore, three such cultivation patterns have been considered in the analysis. Moreover, the major food crop of Nepal being rice, this study has focused the food security issue with respect to rice.

The per capita rice demand of Nepal is assumed to be 93.4 kg/yr. (IRRN, 1999) Taking the reference to The Western Kamala Irrigation project report, Bagmati Irrigation project report and National average report of rice consumption the per unit productivity is calculated in Metric Tons (MT) and is co-rrelated to the number of people can be benefited.

# CHAPTER-V

# RESULTS AND DISCUSSION

## 5.1 Rainfall Analysis

Marine River is a major tributary of the Bagmati River. There is no any raingauge station in the Marine River basin. Being close to the Marine River basin, rainfall data of Hariharpurgadhi (Index No. 1117) and Sindhuligadi (Index No. 1107) were considered as the representative rainfall data for this basin. The rainfall data of the period from 1976 to 2005 has been obtained from DHM. The average annual rainfall of these two stations has been presented in **Figure 5-1** below**.** It shows that the annual rainfall in the basin varies from 1,724 mm (driest year) to 3,320 mm (wettest year) with 2,580 mm as the annual average value. The highest 24-hour rainfall ever recorded at Hariharpurgadhi station is 482.2 mm on July 20, 1993 (DHM, 1999). The normal annual rainfall of Nepal is 1,861.3 mm (Practical Action, 2009); comparing the average annual rainfall of 2,580 mm of the Marine Basin with the national average, this basin falls under high rainfall receiving basin. Further, it also drops under high rainfall intensity area.

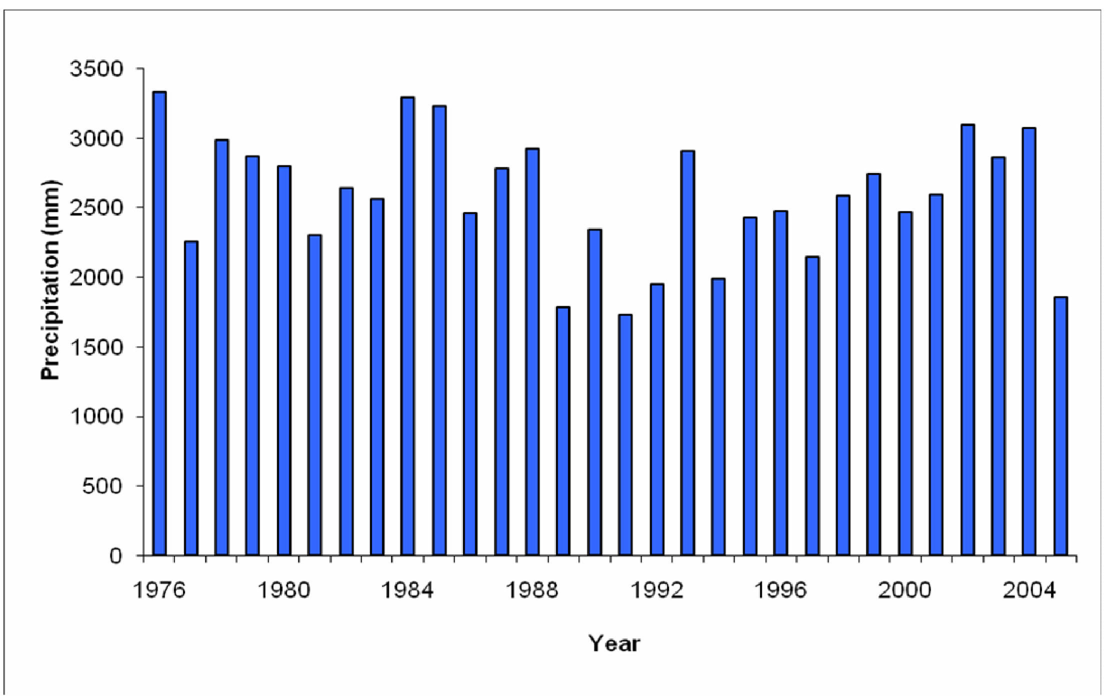



**Figure 5-1: Average annual rainfall of the basin area**

Frequency analysis was carried out using 24 hour maximum rainfall based on the data recorded at Hariharpurgadi using Gumbel distribution. The 24 hour maximum rainfall for different return periods are presented in **Table 5-1** and in **Figure 5-2** below. The result shows that the 24 hour maximum rainfall for 15, 25 and 100 years return period is 369.9 mm, 448.3 mm and 583.8 mm respectively. It indicates the probability of having high flow in the Marine River in monsoon because of rain shower.

**Table 5-1: 24 hour maximum rainfall for different return periods**

| Return Period (T) | 24 hour Maximum Rainfall (Xt) |
|---|---|
| 2 | 185.6 |
| 5 | 292.2 |
| 10 | 362.8 |
| 15 | 402.6 |
| 20 | 425.9 |
| 25 | 451.9 |
| 50 | 518.1 |
| 100 | 583.8 |
| 200 | 660.01 |

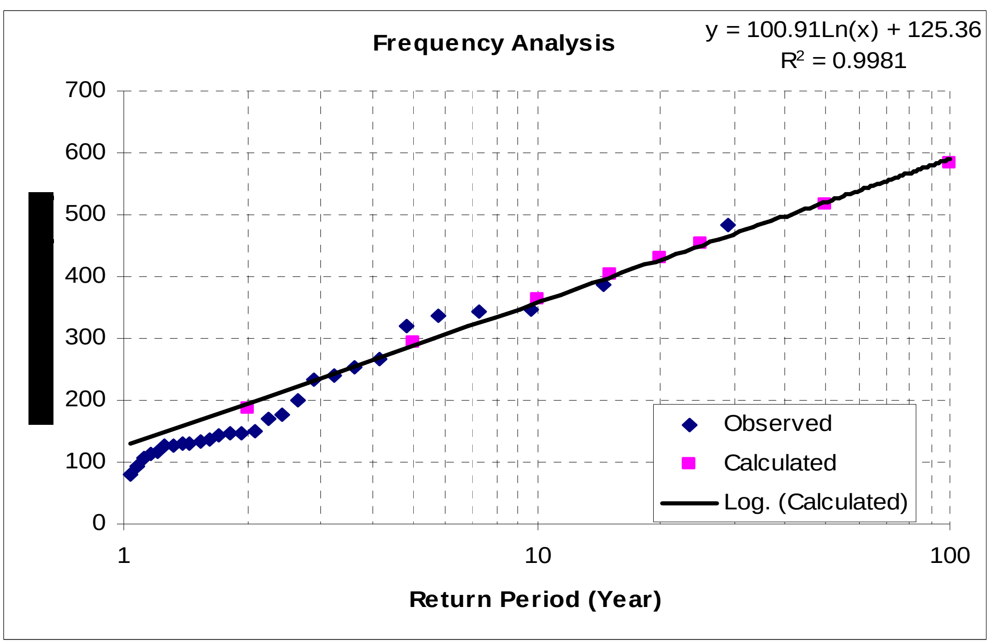



**Figure 5-2: 24 hour maximum rainfall for different return periods**

The mean monthly rainfall of the study area was estimated from the 30 years data (1976-2005) of nearby rainfall stations viz. Hariharpurgadhi and Sindhuligadi and has plotted in **Figure 5-2**. The study area receives 82% of the annual rainfall in monsoon season (June - September). Among the monsoon months, July is the wettest month which receives nearly 747.5 mm (i.e. 28% of the total annual rainfall). Likewise, November is the driest month which receives 11.3 mm (i.e. < 1% of the total annual rainfall).

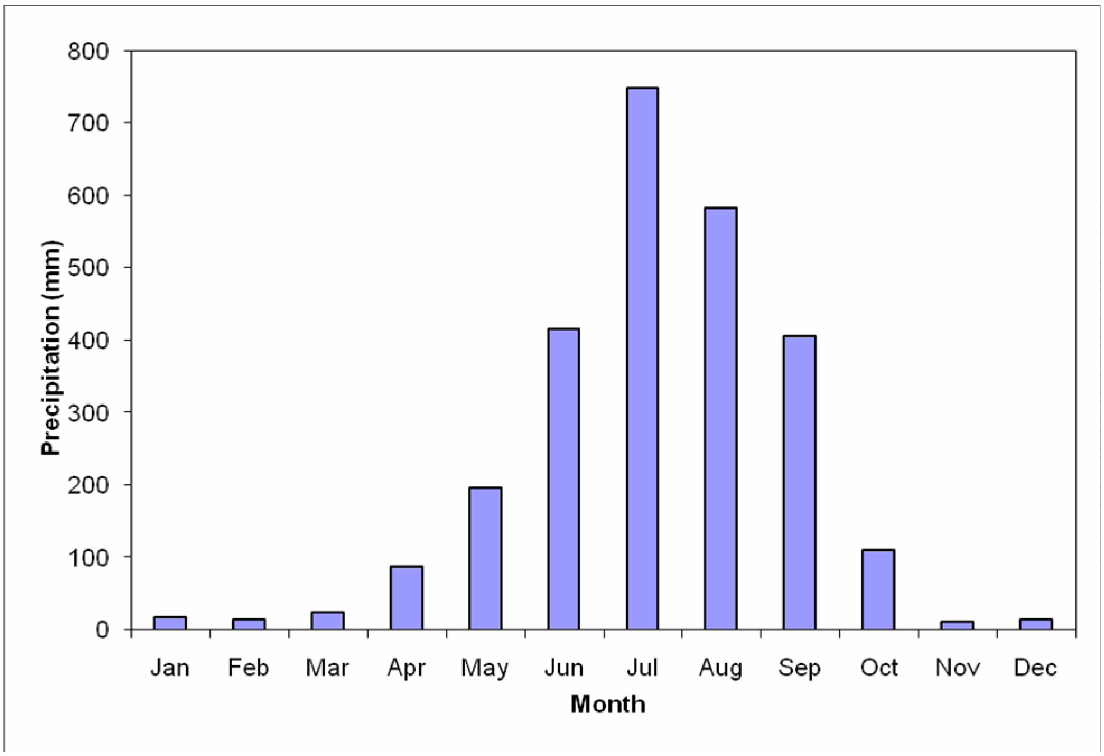



**Figure 5-3: Mean Monthly Rainfall of Marine River basin**

## 5.2 Flow Analysis

The Marine River originates from Mahabharat hills and flows to the south east direction before it reaches the plain region from where it changes direction and flows towards west until it joins the Bagmati River. A number of tributaries contribute flow and sediments to the Marine River. The basin areas and the Marine River bank-side of the confluence to Bagmati River are given in **Table 5-2.** Among them the Ghaghar Khola has the largest area of 55.84 $km^2$.This joins the Marine River from left bank. Telani Khola has least area of about 6.21 $km^2$. This shows that d/s from the confluence with Ghaghar Khola the Marine River will have devastating flood scenario and also Phulbari Khola does nearly the same.

**Table 5-2: The major tributaries of the Marine River and their basins areas**

| S. N. | Tributaries | Catchment Area ($km^2$) | Bank |
|---|---|---|---|
| 1 | Ghaghar Khola | 55.84 | Left |
| 2 | Khanjani Khola | 13.43 | Left |
| 3 | Phulbari Khola | 37.29 | Left |
| 4 | Maruwa Khola | 19.28 | Left |
| 5 | Sukhe Khola | 6.52 | Left |
| 6 | Deujor Khola | 12.9 | Right |
| 7 | Maheshota Khola | 18.74 | Right |
| 8 | Chanduli Khola | 20.52 | Right |
| 9 | Telani Khola | 6.21 | Right |
| 10 | Thulo Garduwa Khola | 11.89 | Right |
| 11 | Sakhauri Khola | 14.51 | Right |
| 12 | Mungre Khola | 18.73 | Right |
| 13 | Sindhure Khola | 19 | Right |
| 14 | Swar khola | 22.35 | Right |
| 15 | Dhanman Khola | 6.68 | Right |
| 16 | Basan Khola | 18.33 | Right |

There is no flow gauging station in the Marine River. DHM (1998) estimated the monthly mean runoffs from the watershed area by using the regression relationship (discharge verses basin area). The monthly discharge thus estimated of this river near the Bhabar is presented in **Figure 5-4**. The average monthly flow comes to be around 22.4$m^3$/s. The variation is very high ranging from 3.16 $m^3$/s in March to 67 $m^3$/s in August. This shows the probability of flooding scenario to be high if the heavy rainfall occurs in monsoon season due to the high lean flow. Mostly the August is highly susceptible to flood.

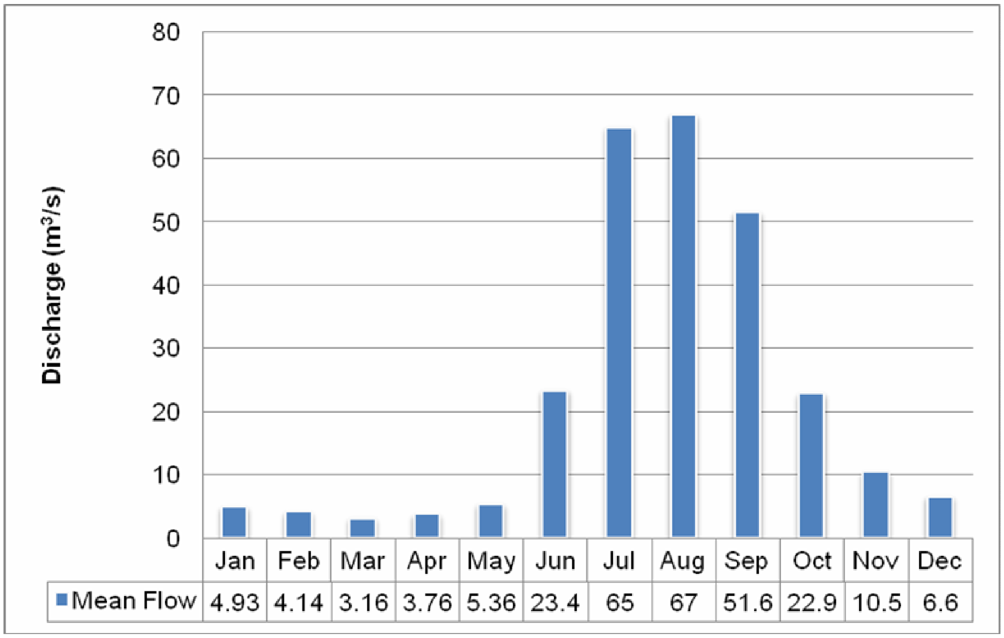



**Figure 5-4: Monthly discharge of the Marine River at Bhabar**

**Table 5-3** and **Figure 5-5** presents the different values of discharges for various return periods of 2, 5, 10, 15, 20, 25, 50, 100 and 200 years by different three methods namely WECS/DHM Method, DHM Method and Modified Dickens Method. Among these the DHM and Modified Dickens methods do not have any significant dissimilarity. Further the discharges of Modified Dickens method are used as the input flood discharges in this study.

**Table 5-3: Marine River discharge at various return periods**

| **S. No.** | **Computation Method** | **Discharge ($m^3$/sec) at various return periods** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **2** | **5** | **10** | **15** | **20** | **25** | **50** | **100** | **200** |
| **1** | WECS/DHM Method | 474.24 | 718.21 | 892.15 | 984.8 | 1066.96 | 1102.92 | 1299.50 | 1492.55 | 1688.29 |
| 2 | DHM Method | 515.68 | 831.50 | 1067.30 | 1194.37 | 1311.40 | 1360.86 | 1645.51 | 1929.94 | 2224.07 |
| 3 | Modified Dickens Method | 513.81 | 831.97 | 1072.65 | 1213.62 | 1313.32 | 1391.03 | 1631.48 | 1872.16 | 2112.83 |

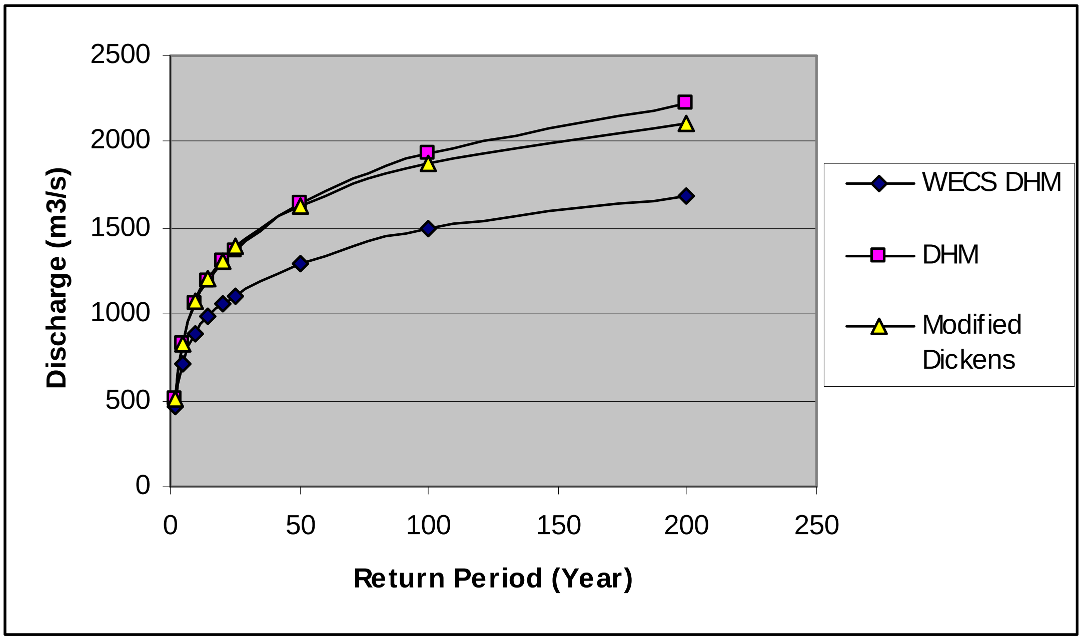



**Figure 5-5: Marine river discharge at various return periods**

Out of the nine various return period's discharges as presented in **Table 5-3** the three different scenarios are studied using the flow data of 15, 25 and 100 year return period only. The reach-wise distributions of the calculated discharge used in the nodes (junctions) as identified in **Figure 4-4** are given in **Table 5-4** below.

**Table 5-4: Reach-wise distribution of the calculated discharge**

| River Reach | Starting Point (Chainage from u/s start | End Point (Chainage from u/s start point) | Reach length (m) | Drainage Area (km2) | Return Periods | | |
|---|---|---|---|---|---|---|---|
| | | | | | 15 yr | 25 yr | 100 yr |
| Reach 1 | 0 | 13951 | 13,951 | 133.15 | 368.77 | 418.05 | 551.8 |
| Reach 2 | 13951 | 16873 | 2,922 | 133 | 664.23 | 757.38 | 1010.16 |
| Reach 3 | 16873 | 21961 | 5,088 | 18.76 | 703.63 | 802.72 | 1071.65 |
| Reach 4 | 21961 | 24544 | 2,583 | 60.31 | 827.54 | 945.45 | 1265.45 |
| Reach 5 | 24544 | 26790 | 2,246 | 25.5 | 878.82 | 1004.56 | 1345.82 |
| Reach 6 | 26790 | 31716 | 4,926 | 18.76 | 916.17 | 1047.63 | 1404.41 |
| Reach 7 | 31716 | 40671 | 8,955 | 49.45 | 1013.21 | 1159.60 | 1538.46 |
| Reach 8 | 40671 | 44328 | 3,657 | 65.85 | 1139.65 | 1305.57 | 1755.85 |
| Reach 9 | 44328 | 46295 | 1,967 | 29.55 | 1195.47 | 1370.05 | 1843.83 |
| Reach 10 | 46295 | 46896 | 601 | 9.57 | 1213.43 | 1390.80 | 1872.17 |
| **Total** | | | **46,896** | **543.9** | **1213.43** | **1390.80** | **1872.17** |

It is seen from **Table 5.4** that almost one third of the total discharge flows in upper portion of the flood prone channel, a specific point has given the name as reach 1 with reach length having 13,951m and basin area 133.15km$^2$. With increasing the drainage area, significant increase in discharges found having 1213.43 m3/s, 1390.8 m3/s and 1872.17 m3/s the total discharges at the outlet for 15, 25 and 100 years return period respectively.

## 5.3 Hydraulic Simulation

Execution of the HEC-RAS model for the three different cases showed varying values of the different hydraulic parameters such as water surface elevation, velocity of channel, flow area etc. The result of the case for 15 yr, 25 yr and 100yr return period has been presented in **ANNEX II**.

## 5.4 Inundation Analysis

The model was run at steady state condition and the flood prone area was delineated for two different cases, namely with and without river training works and the output was imported in HEC-GeoRAS for further processing.

Initially, the model was run to calculate the water surface profiles for the discharges of different return periods. The longitudinal profile of the flow for the flood of 25 and 100 year and typical cross section for 15, 25 and 100 year return period are shown in **Figure 5-6** and **Figure 5-7** respectively. The longitudinal profile demonstrates the average slope of the Marine River designating 0.035. The typical cross-section map without the river training structures (**Figure: 5-7**) shows that the river span is more than 400 m. As the inundation depth increase the span has also increased significantly.

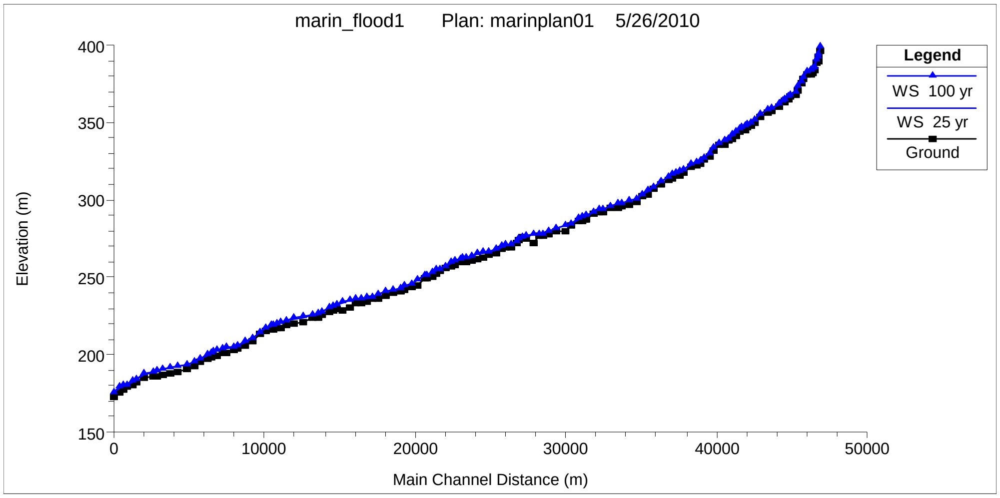
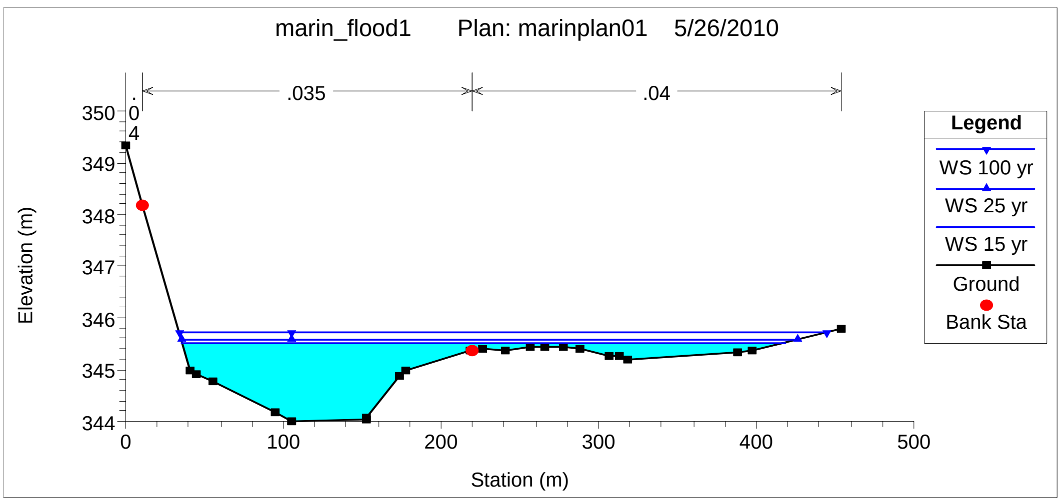



**Figure 5-6: L-profile of the river without river training works**




River Station (Chainage): 39014.91

**Figure 5-7: Typical cross sections of the flow without river training works**

Use of HEC-GeoRAS for inundation analysis with the results obtained from HEC-RAS simulation was applied for flood zonation. Consequently the results derived with the construction of levees at appropriate locations were used to determine the areas of reclaimed land. The **Figure 5-8, Figure 5-9 and Figure 5-10** below show the inundation maps without the river training structures for 15, 25 and 100 year return periods respectively. **Figure 5-11** is the inundation map for 100 year return period in the presence of river training structure.

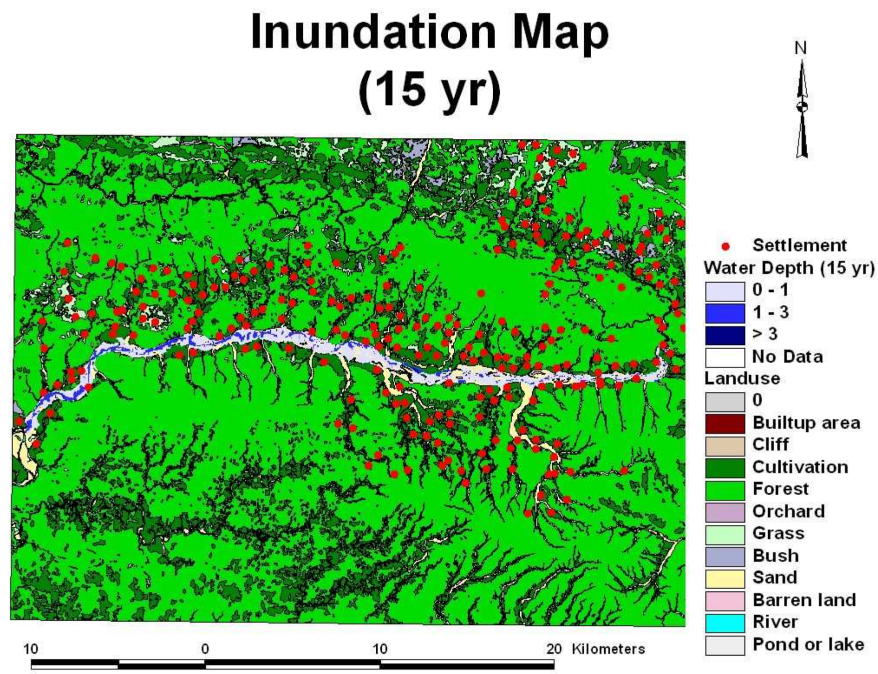



**Figure 5-8: Inundation map for 15 year return period**

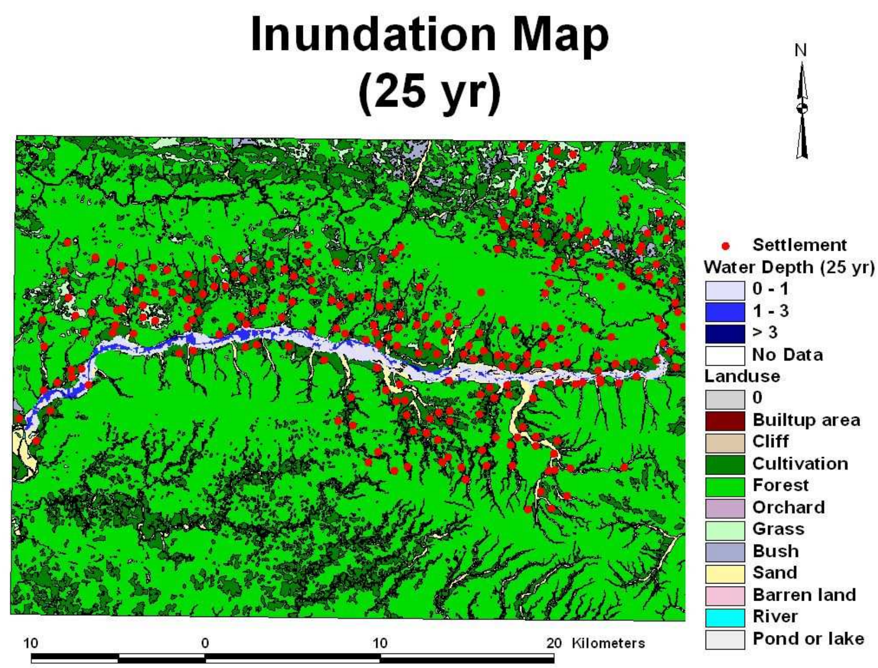



**Figure 5-9: Inundation map for 25 year return period**

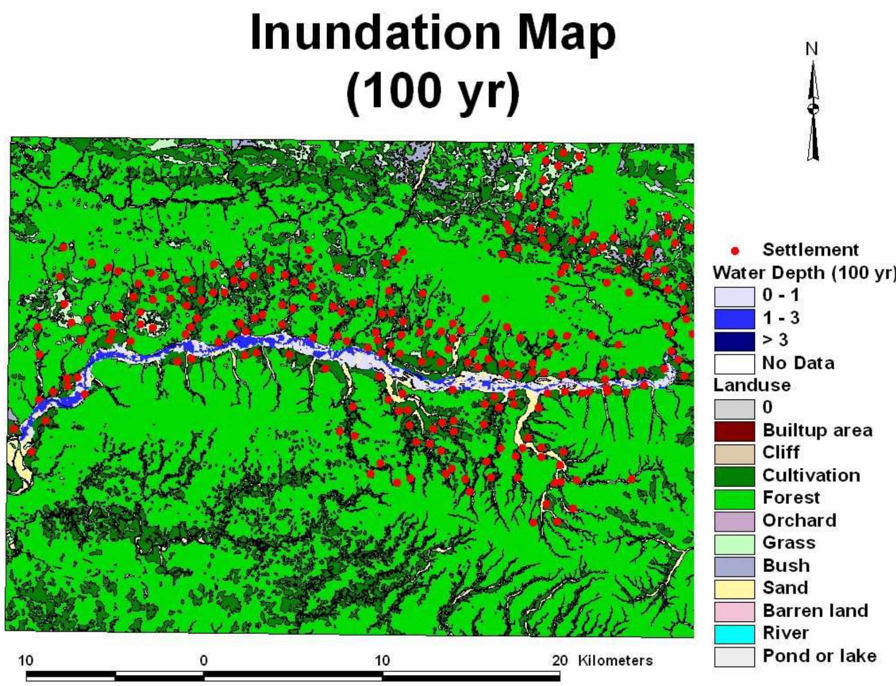



**Figure 5-10: Inundation map for 100 year return period**

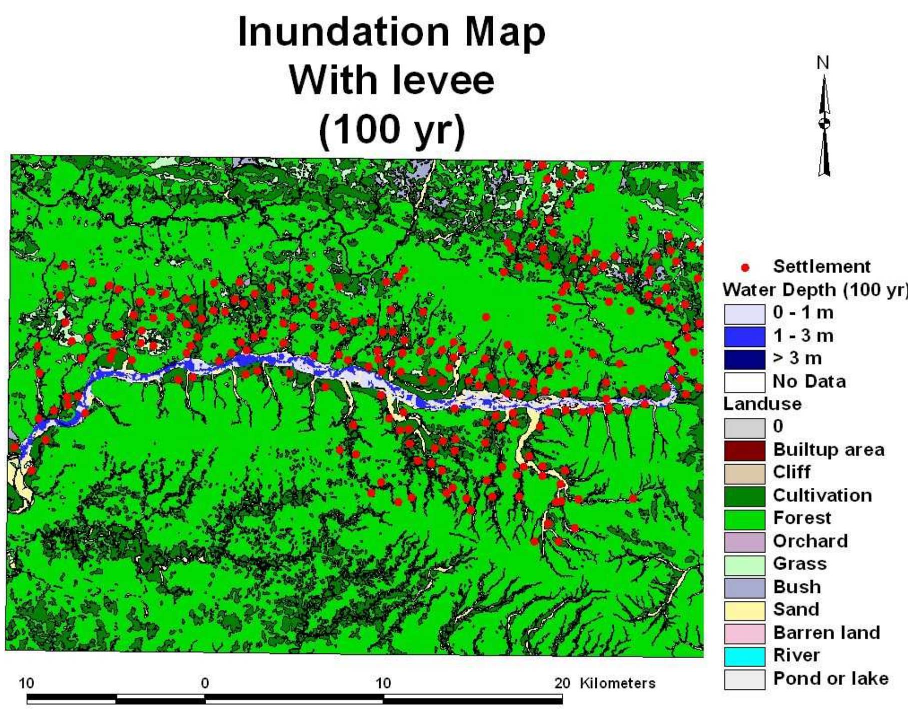



**Figure 5-11: Inundation map for 100 yr return period with levee**

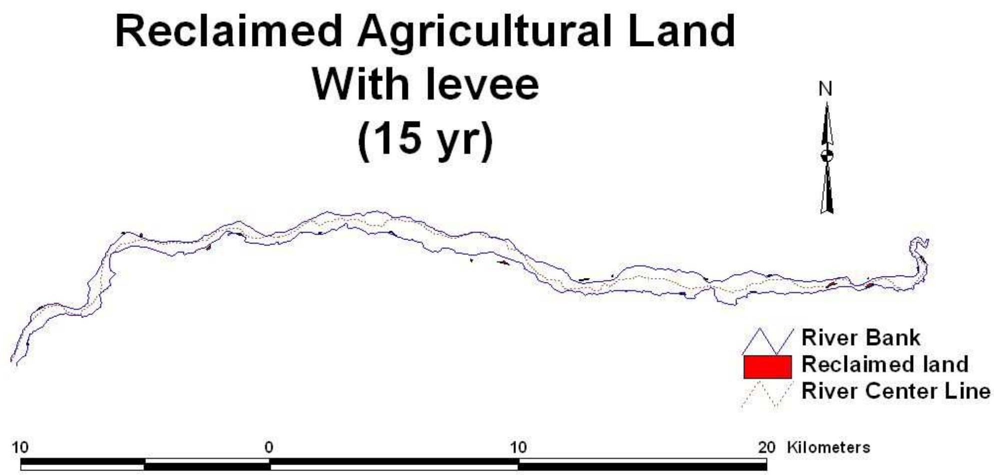



**Figure 5-12: Reclaimed Agricultural Land with levee for 15 year return period.**

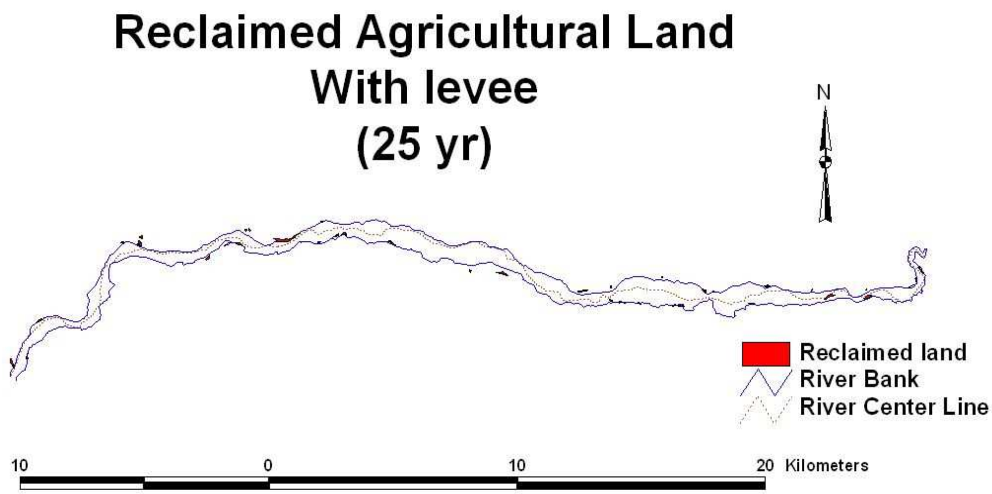



**Figure 5-13: Reclaimed Agricultural Land with levee for 25 year return period.**

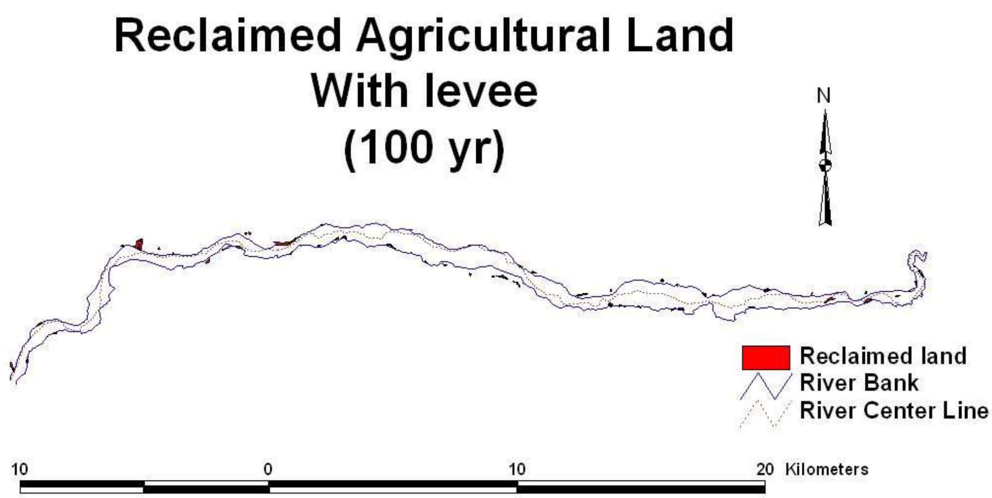



**Figure 5-14: Reclaimed Agricultural land for 100 year return period**

The pictorial representation of the output of HEC-GeoRAS as drawn above (**Figure 5-8, Figure 5-9 and Figure 5-10**) shows that the total area inundated without any river training structures for the different return period of 15, 25 and 100 years are 2182.36, 2259.09 and 2442.52 ha respectively. The area of inundation depth below 3m and more than 3m has also noticeably increased as the return period flood increases. The inundation map after the levees proposed for only 100 year return period is given in **Figure 5-11.** This shows that the depth of inundation has significantly increased but the inundated area is significantly reduced. Since the Levees are only proposed to socio-economically valuable areas hence total inundated area is much more than the area reclaimed. No settlement area is inundated within 100 year return period flood. **Figure 5-12**, **Figure 5-13** and **Figure 5-14** illustrate the reclaimed land for 15, 25 and 100 year return period flood. The same as the inundated area the reclaimed areas are also increasing as the return period flood increases. The total reclaimed land for the different return period of 15, 25 and 100 years are 229.21, 237.27 and 289.56 ha respectively. Further, the total agricultural land reclaimed for these return periods are 218.52, 224.79 and 251.50 ha respectively. The **Table 5-5** below depicted the details of the reclaimed land which are plotted in graphical way in **Figure 5-15** where Series 1 denotes the line of reclaimed agricultural land for various return period.

**Table 5-5: Reclaimed lands for different scenarios**

| Return Period (yr) | Total area inundated without levee (ha) | Total area inundated after levee (ha) | Total area reclaimed (ha) | Agricultural land inundated without levee (ha) | Agricultural land inundated after levee (ha) | Total agricultural area reclaimed (ha) |
|---|---|---|---|---|---|---|
| 15 | 2182.36 | 1953.15 | 229.21 | 237.20 | 18.68 | 218.52 |
| 25 | 2259.09 | 2021.82 | 237.27 | 249.47 | 24.68 | 224.79 |
| 100 | 2442.52 | 2152.96 | 289.56 | 303.65 | 52.15 | 251.50 |

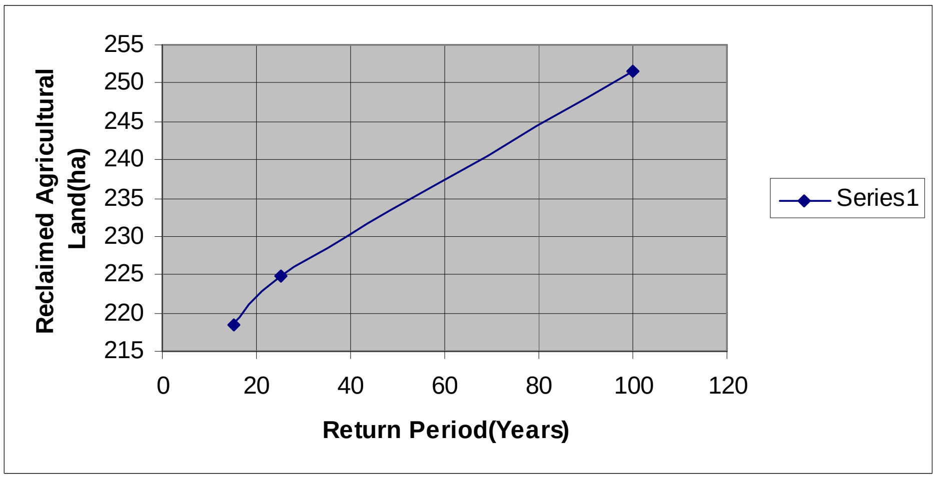



**Figure 5-15: Reclaimed Agricultural land for different return period**

## 5.5 Food Security

As Nepal's economy is dependent mostly on agriculture, the reclaimed land was associated with its agricultural productivity. Since the floodplain areas are formed by the deposition of fine sediment, it is extremely fertile. Such fertile land has productivity much higher than other areas.

The cropping pattern in the Nepalese context is to farm three different cereal crops, i.e. rice, wheat and maize annually. Plantation of rice for two seasons is possible along with a single season of wheat in the floodplain area. Moreover, the major food crop of Nepal being rice, this study has focused the food security issue with respect to rice. The table below shows the annual yield per hectare considering the two different zones and the national average. The yield of hybrid crops has been found to be much more than the indigenous crops. Hence, the productivity of both the hybrid and indigenous crops has been analyzed and the results are shown in the following table.

For the purpose the per unit yield of rice and wheat of Western Kamala Irrigation Project, Bagmati Irrigation Project and National Average of Hybrid and Indigenous having the values 2.95, 5.25, 6.236 and 2.06 MT/ha are taken as the reference for food security analysis. The yield data are presented in **Table 5-6**.

**Table 5-6: Per unit yield of different zones**

| Crop | Yield (MT/ha) | | | | |
|---|---|---|---|---|---|
| | Western Kamala Irrigation Project | Bagmati Irrigation Project | National Average | | |
| | | | Hybrid | Indigenous | |
| Rice | 2.95 | 5.25 | 6.24 | 2.06 | |

(Source: DOI, 2009)

The given per unit yield was correlated with the total Agricultural land reclaimed (**Table 5-5**). Hence the total production in Metric Tons (MT) for each of the land reclaimed for 15, 25 and 100 year return period was calculated and presented in **Table 5-7, Table 5-8 and Table 5-9** below. For the reclaimed land of 15 year case, Western Kamala Irrigation Project, Bagmati Irrigation Project, National Average (Hybrid) and National Average (Indigenous) have the Productivity of rice 644.634, 1147.23, 1362.69 and 450.37 Metric Tons (MT) respectively. The 25 and 100 year cases have these values 663.13, 1180.15, 1401.79, 463.29 Metric Tons and 741.92, 1320.38, 1568.35, 518.34 Metric Tons (MT) respectively. This shows the production considering National average for Hybrid is seen more beneficial in each of the three cases among them.

**Table 5-7: Total Productivity (MT) in Land reclaimed for 15 year flood**

| Crop | Western Kamala Irrigation Project | Bagmati Irrigation Project | National Average (Nepal) | |
|---|---|---|---|---|
| | | | Hybrid | Indigenous |
| Rice | 644.63 | 1147.23 | 1362.69 | 450.37 |

**Table 5-8: Total Productivity (MT) in Land reclaimed for 25 year flood**

| Crop | Western Kamala Irrigation Project | Bagmati Irrigation Project | National Average (Nepal) | |
|---|---|---|---|---|
| | | | Hybrid | Indigenous |
| Rice | 663.13 | 1180.115 | 1401.79 | 463.29 |

**Table 5-9: Total Productivity (MT) in Land reclaimed for 200 year flood**

| Crop | Western Kamala Irrigation Project | Bagmati Irrigation Project | National Average(Nepal) | |
|---|---|---|---|---|
| | | | Hybrid | Indigenous |
| Rice | 741.92 | 1320.38 | 1568.35 | 518.34 |

Per capita rice demand of Nepal is 93.4 kg/year (IRRN, 1999). This value has been used to calculate the total number of people can be benefited in the Marine River Basin. Since the total population in Marine River Basin is 91579 **(Table 3-4)**. Hence the percentage of people there can be fed has also been calculated. The details are presented in **Table 5-10.**

**Table 5-10: Food Security considering rice**

| No. of people Benefited by | Western Kamala Irrigation Project | Bagmati Irrigation Project | National Average (hybrid) | National Average (indigenous) |
|---|---|---|---|---|
| Reclaimed land of 15 year flood | 6862 (7.5%) | 12204 (13.3%) | 14497 (15.8%) | 4791 (5.2%) |
| Reclaimed land of 25 year flood | 7055 (7.7%) | 12554 (13.7%) | 14913 (16.3%) | 4926 (5.4%) |
| Reclaimed land of 100 year flood | 7894 (8.6%) | 14047 (15.4%) | 16685 (18.2%) | 5510 (6%) |

The number and percentage (%) of people of the basin can be benefited are presented in **Table 5-10** for each 15, 25 and 100 year case. The food security considering the National Average (Hybrid) shows 15.8%, 16.3% and 18.2% of the total population of the basin can be benefited for 15, 25 and 100 year case correspondingly is the optimum case. Hence Hybrid rice can be recommended for plantation.

# CHAPTER-VI

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

The major portion of Marine River lies in the Siwalik range that is having relatively soft rocks and the river flows through the old river terrace and occasionally encounters the Siwaliks rocks. Marine River generally exhibit braded nature with constantly shifting its channel and is meandered at some location. In the past, the river has severely affected the fertile agricultural land situated on either banks of the river. Thus the integrated impact is a complex, resulting the planning and implementing river training works a challenging task. Based on the past Hydrological events of Marine River and present condition, the following conclusions can be drawn through the present study:

- Natural Disasters like floods, landslides, river bank erosion, debris flow, soil erosion, etc have posed threats to the socio-economic circumstance causing considerable loss of agricultural land, food production, private properties and lives in Marine River Basin. Hence, reducing the impact of these natural disasters triggered by human interference is an indispensable task for preparing the river Training plan of Marine River and executing the plan is essential to reduce these threats of floods and inundation.
- The extent of flood hazard in Marine River basin for the various return period shows that the total hazard area increases as the return periods. The high intensity rainfall of the Marine basin leads to flash flood with high value of discharge.
- Hydraulic simulation of the 15, 25 and 100 year return period case showed that a considerable area of fertile land will be inundated in rapid ascending order as the return period increases. Besides, the proposed river training structures in the Marine River explicitly demonstrates the relationship among the parameters, viz, rainfall intensity, flood inundation and reclaimed land and economic value with respect to food security considering rice.

## 6.2 Recommendations

The following recommendations can be drawn from the results and discussion made in the previous chapters.

- It is better to employ the River Training Works in the Marine River in line with the Integrated Water Resources Management, not in isolated form.
- The watershed management should be implemented to control runoff and erosion by enforcing land use regulation, conservation of open land and conservation of forest.
- It is recommended to study the food security issue not only concerning with rice but also with wheat, maize, potatoes and other crops there can be cultivated.
- The reclaimed land obtained after the river training works can be utilized for agriculture purpose, especially to cultivate high value crops, such as hybrid rice and hybrid wheat, fish farming and/or industrial and commercial purposes.
- The impact of climate change on the water resources in the basin should be taken into consideration to get the enhanced projection for the design and implementation of River Training works.
- It is recommended to study the other meteorological, geological and Socio-economic parameter of the basin to get more reliable information that can be the important gear for the further study.

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# ANNEXES

# ANNEXE 1: MANNING'S 'n' VALUES

**Manning's n for natural channel**

| Type of Channel and Description | Minimum | Normal | Maximum |
|---|---|---|---|
| **1. Natural streams - minor streams (top width at flood stage < 100 ft)** | | | |
| **I. Main Channels** | | | |
| a. Clean, straight, full stage, no rifts or deep pools | 0.025 | 0.030 | 0.033 |
| b. Same as above, but more stones and weeds | 0.030 | 0.035 | 0.040 |
| c. Clean, winding, some pools and shoals | 0.033 | 0.040 | 0.045 |
| d. Same as above, but some weeds and stones | 0.035 | 0.045 | 0.050 |
| e. Same as above, lower stages, more ineffective slopes and sections | 0.040 | 0.048 | 0.055 |
| f. Same as "d" with more stones | 0.045 | 0.050 | 0.060 |
| g. Sluggish reaches, weedy, deep pools | 0.050 | 0.070 | 0.080 |
| h. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush | 0.075 | 0.100 | 0.150 |
| **II. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages** | | | |
| a. Bottom: gravels, cobbles, and few boulders | 0.030 | 0.040 | 0.050 |
| b. Bottom: cobbles with large boulders | 0.040 | 0.050 | 0.070 |
| **3. Floodplains** | | | |
| a. Pasture, no brush | | | |
| 1.Short grass | 0.025 | 0.030 | 0.035 |
| 2. High grass | 0.030 | 0.035 | 0.050 |
| b. Cultivated areas | | | |
| 1. No crop | 0.020 | 0.030 | 0.040 |
| 2. Mature row crops | 0.025 | 0.035 | 0.045 |
| 3. Mature field crops | 0.030 | 0.040 | 0.050 |
| c. Brush | | | |
| 1. Scattered brush, heavy weeds | 0.035 | 0.050 | 0.070 |
| 2. Light brush and trees, in winter | 0.035 | 0.050 | 0.060 |
| 3. Light brush and trees, in summer | 0.040 | 0.060 | 0.080 |
| 4. Medium to dense brush, in winter | 0.045 | 0.070 | 0.110 |
| 5. Medium to dense brush, in summer | 0.070 | 0.100 | 0.160 |
| d. Trees | | | |

| | | | |
|---|---|---|---|
| 1. Dense willows, summer, straight | 0.110 | 0.150 | 0.200 |
| 2. Cleared land with tree stumps, no sprouts | 0.030 | 0.040 | 0.050 |
| 3. Same as above, but with heavy growth of sprouts | 0.050 | 0.060 | 0.080 |
| 4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches | 0.080 | 0.100 | 0.120 |
| 5. Same as 4. with flood stage reaching branches | 0.100 | 0.120 | 0.160 |
| **4. Major streams (top width at flood stage > 100ft)** | | | |
| a. Regular section with no boulders or brush | 0.025 | | 0.060 |
| b. Irregular and rough section | 0.035 | | 0.100 |

# ANNEX 2: HYDRAULIC SIMULATION

**HEC-RAS model output of the hydraulic parameters**

| River Sta | Profile | Q Total | Min Ch El | W.S. Elev | Vel Chnl | Flow Area | Top Width | Froude # Chl |
|---|---|---|---|---|---|---|---|---|
| | | (m3/s) | (m) | (m) | (m/s) | (m2) | (m) | |
| | | | | | | | | |
| 46939.29 | 15 yr | 368.77 | 396.22 | 398.65 | 3.9 | 95.65 | 63.25 | 1.01 |
| 46939.29 | 25 yr | 418.05 | 396.22 | 398.79 | 4.03 | 104.83 | 65.95 | 1.01 |
| 46939.29 | 100 yr | 551.8 | 396.22 | 399.14 | 4.36 | 129.3 | 70.16 | 0.99 |
| | | | | | | | | |
| 46840.24 | 15 yr | 368.77 | 392.37 | 393.86 | 8.04 | 50.54 | 65.31 | 2.68 |
| 46840.24 | 25 yr | 418.05 | 392.37 | 393.94 | 8.29 | 55.79 | 67.89 | 2.68 |
| 46840.24 | 100 yr | 551.8 | 392.37 | 394.12 | 8.93 | 68.83 | 76.7 | 2.72 |
| | | | | | | | | |
| 46774.15 | 15 yr | 368.77 | 389.96 | 392 | 5.03 | 78.96 | 95.05 | 1.55 |
| 46774.15 | 25 yr | 418.05 | 389.96 | 392.07 | 5.29 | 85.94 | 98.45 | 1.59 |
| 46774.15 | 100 yr | 551.8 | 389.96 | 392.24 | 5.88 | 103.69 | 106.51 | 1.67 |
| | | | | | | | | |
| 46699.1 | 15 yr | 368.77 | 388.23 | 390.67 | 3.85 | 101.37 | 111.86 | 1.22 |
| 46699.1 | 25 yr | 418.05 | 388.23 | 390.74 | 4.03 | 109.67 | 112.64 | 1.24 |
| 46699.1 | 100 yr | 551.8 | 388.23 | 390.92 | 4.48 | 130.28 | 114.57 | 1.28 |
| | | | | | | | | |
| 46592.88 | 15 yr | 368.77 | 383.95 | 385.11 | 7.13 | 51.71 | 60.94 | 2.47 |
| 46592.88 | 25 yr | 418.05 | 383.95 | 385.2 | 7.28 | 57.45 | 62.53 | 2.42 |
| 46592.88 | 100 yr | 551.8 | 383.95 | 385.44 | 7.6 | 72.7 | 66.56 | 2.31 |
| 46432.78 | 15 yr | 368.77 | 382 | 384.29 | 1.62 | 227.02 | 132.58 | 0.4 |
| 46432.78 | 25 yr | 418.05 | 382 | 384.4 | 1.73 | 242.09 | 134.1 | 0.41 |
| 46432.78 | 100 yr | 551.8 | 382 | 384.67 | 1.98 | 278.27 | 137.67 | 0.45 |
| | | | | | | | | |
| 46362.79 | 15 yr | 368.77 | 382 | 383.67 | 3.07 | 120.02 | 125.84 | 1 |
| 46362.79 | 25 yr | 418.05 | 382 | 383.77 | 3.15 | 132.84 | 129.17 | 0.99 |
| 46362.79 | 100 yr | 551.8 | 382 | 384.13 | 3.07 | 180.7 | 138.64 | 0.84 |
| | | | | | | | | |
| 46280.77 | 15 yr | 368.77 | 381 | 383.63 | 1.56 | 235.72 | 133.34 | 0.38 |
| 46280.77 | 25 yr | 418.05 | 381 | 383.77 | 1.64 | 254.39 | 135.87 | 0.38 |
| 46280.77 | 100 yr | 551.8 | 381 | 384.11 | 1.83 | 302.01 | 141.69 | 0.4 |
| | | | | | | | | |
| 46061.6 | 15 yr | 368.77 | 381 | 382.46 | 3.33 | 110.7 | 99.09 | 1.01 |
| 46061.6 | 25 yr | 418.05 | 381 | 382.57 | 3.46 | 120.91 | 99.27 | 1 |
| 46061.6 | 100 yr | 551.8 | 381 | 382.81 | 3.79 | 145.69 | 99.72 | 1 |
| | | | | | | | | |
| 45851.02 | 15 yr | 368.77 | 377.75 | 378.95 | 3.28 | 112.47 | 184.57 | 1.34 |
| 45851.02 | 25 yr | 418.05 | 377.75 | 378.98 | 3.53 | 118.49 | 185.31 | 1.41 |
| 45851.02 | 100 yr | 551.8 | 377.75 | 379.07 | 4.08 | 135.11 | 187.35 | 1.54 |
| | | | | | | | | |
| 45703.99 | 15 yr | 368.77 | 375.03 | 376.41 | 2.7 | 136.74 | 201.66 | 1.05 |
| 45703.99 | 25 yr | 418.05 | 375.03 | 376.49 | 2.73 | 153.13 | 202.88 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 45703.99 | 100 yr | 551.8 | 375.03 | 376.65 | 2.99 | 185.04 | 205.42 | 1 |
| | | | | | | | | |
| 45467.45 | 15 yr | 368.77 | 371 | 373.22 | 3.29 | 111.98 | 101.01 | 1 |
| 45467.45 | 25 yr | 418.05 | 371 | 373.38 | 3.2 | 130.56 | 124.18 | 1 |
| 45467.45 | 100 yr | 551.8 | 371 | 373.61 | 3.42 | 161.5 | 140.95 | 1.02 |
| | | | | | | | | |
| 45268.34 | 15 yr | 368.77 | 368 | 370.36 | 1.8 | 205.02 | 286.07 | 0.68 |
| 45268.34 | 25 yr | 418.05 | 368 | 369.71 | 4.31 | 96.95 | 98.65 | 1.39 |
| 45268.34 | 100 yr | 551.8 | 368 | 370.12 | 3.78 | 145.91 | 191.43 | 1.38 |
| | | | | | | | | |
| 44956.28 | 15 yr | 368.77 | 366.73 | 367.44 | 2.17 | 176.27 | 362.99 | 1.01 |
| 44956.28 | 25 yr | 418.05 | 366.73 | 367.49 | 2.22 | 195.56 | 366.92 | 0.98 |
| 44956.28 | 100 yr | 551.8 | 366.73 | 367.64 | 2.23 | 253.05 | 392.97 | 0.91 |
| | | | | | | | | |
| 44843.64 | 15 yr | 368.77 | 365 | 366.69 | 1.88 | 226.6 | 279.08 | 0.63 |
| 44843.64 | 25 yr | 418.05 | 365 | 366.76 | 1.95 | 247.72 | 290.6 | 0.64 |
| 44843.64 | 100 yr | 551.8 | 365 | 366.91 | 2.18 | 293.33 | 314.47 | 0.68 |
| | | | | | | | | |
| 44619.06 | 15 yr | 368.77 | 364.14 | 365.09 | 2.34 | 164.95 | 297.98 | 1.01 |
| 44619.06 | 25 yr | 418.05 | 364.14 | 365.14 | 2.47 | 178.77 | 304.1 | 1.03 |
| 44619.06 | 100 yr | 551.8 | 364.14 | 365.28 | 2.62 | 225.46 | 362.5 | 1 |
| | | | | | | | | |
| 44519.48 | 15 yr | 368.77 | 363.5 | 364.43 | 1.13 | 368.7 | 634.93 | 0.45 |
| 44519.48 | 25 yr | 418.05 | 363.5 | 364.48 | 1.19 | 398.27 | 644.02 | 0.46 |
| 44519.48 | 100 yr | 551.8 | 363.5 | 364.59 | 1.33 | 470.45 | 658.66 | 0.47 |
| | | | | | | | | |
| 44413.54 | 15 yr | 368.77 | 363.18 | 363.74 | 1.65 | 198.65 | 552.94 | 1.01 |
| 44413.54 | 25 yr | 418.05 | 363.18 | 363.77 | 1.76 | 216.17 | 561.7 | 1.02 |
| 44413.54 | 100 yr | 551.8 | 363.18 | 363.85 | 1.99 | 263.23 | 590.38 | 1.05 |
| | | | | | | | | |
| 44185.33 | 15 yr | 368.77 | 360.18 | 361.52 | 1.58 | 237.23 | 356.4 | 0.64 |
| 44185.33 | 25 yr | 418.05 | 360.18 | 361.57 | 1.65 | 256.96 | 367.71 | 0.65 |
| 44185.33 | 100 yr | 551.8 | 360.18 | 361.74 | 1.61 | 325.57 | 451.29 | 0.65 |
| | | | | | | | | |
| 43759.63 | 15 yr | 368.77 | 357 | 358.93 | 1.52 | 241.12 | 421.26 | 0.65 |
| 43759.63 | 25 yr | 418.05 | 357 | 358.98 | 1.57 | 266.2 | 439.55 | 0.65 |
| 43759.63 | 100 yr | 551.8 | 357 | 359.11 | 1.7 | 323.56 | 475.8 | 0.66 |
| | | | | | | | | |
| 43446.59 | 15 yr | 368.77 | 356.12 | 357.88 | 0.93 | 374.22 | 605.28 | 0.39 |
| 43446.59 | 25 yr | 418.05 | 356.12 | 357.93 | 0.97 | 410.12 | 635.71 | 0.4 |
| 43446.59 | 100 yr | 551.8 | 356.12 | 358.06 | 1.09 | 488.07 | 647.15 | 0.41 |
| | | | | | | | | |
| 42952.94 | 15 yr | 368.77 | 354 | 355.37 | 2.1 | 175.25 | 399.39 | 1.01 |
| 42952.94 | 25 yr | 418.05 | 354 | 355.41 | 2.18 | 191.75 | 403.11 | 1.01 |
| 42952.94 | 100 yr | 551.8 | 354 | 355.51 | 2.38 | 232.33 | 412.09 | 1.01 |
| | | | | | | | | |
| 42570.16 | 15 yr | 368.77 | 350 | 351.87 | 1.53 | 241.72 | 300.55 | 0.54 |
| 42570.16 | 25 yr | 418.05 | 350 | 351.94 | 1.58 | 264.84 | 312.88 | 0.55 |
| 42570.16 | 100 yr | 551.8 | 350 | 352.12 | 1.71 | 323.17 | 343.92 | 0.56 |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 42295.34 | 15 yr | 368.77 | 348 | 349.82 | 2.57 | 143.26 | 214.62 | 1.01 |
| 42295.34 | 25 yr | 418.05 | 348 | 349.89 | 2.65 | 157.75 | 225.4 | 1.01 |
| 42295.34 | 100 yr | 551.8 | 348 | 350.05 | 2.84 | 194.52 | 240.29 | 1.01 |
| | | | | | | | | |
| 42127.53 | 15 yr | 368.77 | 347 | 348.86 | 1.44 | 259.45 | 277.72 | 0.48 |
| 42127.53 | 25 yr | 418.05 | 347 | 348.93 | 1.52 | 278.69 | 282.96 | 0.49 |
| 42127.53 | 100 yr | 551.8 | 347 | 349.1 | 1.7 | 328.03 | 295.97 | 0.52 |
| | | | | | | | | |
| 41903.67 | 15 yr | 368.77 | 345 | 347.59 | 2.32 | 164 | 250.8 | 0.88 |
| 41903.67 | 25 yr | 418.05 | 345 | 347.67 | 2.38 | 182.42 | 256.07 | 0.86 |
| 41903.67 | 100 yr | 551.8 | 345 | 347.85 | 2.52 | 229.71 | 269.14 | 0.82 |
| | | | | | | | | |
| 41721.48 | 15 yr | 368.77 | 345 | 346.45 | 1.89 | 194.94 | 200.96 | 0.61 |
| 41721.48 | 25 yr | 418.05 | 345 | 346.53 | 1.98 | 211.34 | 209.73 | 0.63 |
| 41721.48 | 100 yr | 551.8 | 345 | 346.71 | 2.2 | 251.11 | 229.6 | 0.67 |
| | | | | | | | | |
| 41532.17 | 15 yr | 368.77 | 344 | 345.52 | 1.99 | 209.71 | 382.01 | 0.65 |
| 41532.17 | 25 yr | 418.05 | 344 | 345.58 | 2.08 | 232.22 | 390.43 | 0.66 |
| 41532.17 | 100 yr | 551.8 | 344 | 345.72 | 2.28 | 289.48 | 411.07 | 0.68 |
| | | | | | | | | |
| 41301.48 | 15 yr | 368.77 | 341.1 | 343.54 | 2.77 | 134.98 | 192.72 | 0.99 |
| 41301.48 | 25 yr | 418.05 | 341.1 | 343.62 | 2.84 | 151.16 | 208.6 | 0.97 |
| 41301.48 | 100 yr | 551.8 | 341.1 | 343.81 | 3 | 194.75 | 246.34 | 0.94 |
| 41083.31 | 15 yr | 368.77 | 339 | 341.55 | 1.92 | 244.78 | 416.16 | 0.62 |
| 41083.31 | 25 yr | 418.05 | 339 | 341.62 | 1.96 | 276.72 | 451.88 | 0.61 |
| 41083.31 | 100 yr | 551.8 | 339 | 341.78 | 2.05 | 352.16 | 480 | 0.6 |
| | | | | | | | | |
| 40822.25 | 15 yr | 368.77 | 338 | 339.63 | 2.84 | 167.75 | 252.94 | 0.95 |
| 40822.25 | 25 yr | 418.05 | 338 | 339.68 | 2.88 | 182.16 | 266.48 | 0.98 |
| 40822.25 | 100 yr | 551.8 | 338 | 339.82 | 2.97 | 220.51 | 299.58 | 1.03 |
| | | | | | | | | |
| 40530.17 | 15 yr | 368.77 | 336 | 337.9 | 1.43 | 263.97 | 257.85 | 0.44 |
| 40530.17 | 25 yr | 418.05 | 336 | 337.99 | 1.49 | 288.15 | 266.58 | 0.44 |
| 40530.17 | 100 yr | 551.8 | 336 | 338.2 | 1.65 | 345.12 | 281.41 | 0.46 |
| | | | | | | | | |
| 40225.69 | 15 yr | 368.77 | 335.52 | 336.7 | 1.99 | 186.9 | 229.07 | 0.71 |
| 40225.69 | 25 yr | 418.05 | 335.52 | 336.76 | 2.1 | 201.03 | 233.18 | 0.73 |
| 40225.69 | 100 yr | 551.8 | 335.52 | 336.93 | 2.31 | 240.08 | 244.17 | 0.75 |
| | | | | | | | | |
| 39862.58 | 15 yr | 368.77 | 331.87 | 333.2 | 2.63 | 140.4 | 205.24 | 1.01 |
| 39862.58 | 25 yr | 418.05 | 331.87 | 333.28 | 2.69 | 155.66 | 212.31 | 1 |
| 39862.58 | 100 yr | 551.8 | 331.87 | 333.44 | 2.88 | 191.42 | 228.13 | 1 |
| | | | | | | | | |
| 39558.29 | 15 yr | 368.77 | 327.8 | 329.76 | 2.01 | 183.76 | 194.42 | 0.66 |
| 39558.29 | 25 yr | 418.05 | 327.8 | 329.84 | 2.1 | 199.06 | 201.33 | 0.67 |
| 39558.29 | 100 yr | 551.8 | 327.8 | 330.02 | 2.33 | 238.18 | 223.23 | 0.7 |
| | | | | | | | | |
| 39276.44 | 15 yr | 368.77 | 326 | 327.34 | 2.53 | 145.9 | 225.29 | 1 |
| 39276.44 | 25 yr | 418.05 | 326 | 327.4 | 2.61 | 160.18 | 231.52 | 1 |
| 39276.44 | 100 yr | 551.8 | 326 | 327.55 | 2.8 | 197.27 | 248.59 | 1 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 39014.91 | 15 yr | 368.77 | 323 | 325.29 | 1.57 | 242.94 | 383.99 | 0.61 |
| 39014.91 | 25 yr | 418.05 | 323 | 325.37 | 1.57 | 275.01 | 418.17 | 0.6 |
| 39014.91 | 100 yr | 551.8 | 323 | 325.53 | 1.63 | 348.32 | 490.74 | 0.61 |
| | | | | | | | | |
| 38749.15 | 15 yr | 368.77 | 322.05 | 324.15 | 1.51 | 260.11 | 402.61 | 0.53 |
| 38749.15 | 25 yr | 418.05 | 322.05 | 324.22 | 1.54 | 291.19 | 436.42 | 0.54 |
| 38749.15 | 100 yr | 551.8 | 322.05 | 324.35 | 1.7 | 350.47 | 455.65 | 0.57 |
| | | | | | | | | |
| 38398.48 | 15 yr | 368.77 | 321.2 | 322.76 | 1.45 | 259.22 | 407.55 | 0.56 |
| 38398.48 | 25 yr | 418.05 | 321.2 | 322.82 | 1.5 | 285.13 | 419.49 | 0.56 |
| 38398.48 | 100 yr | 551.8 | 321.2 | 322.98 | 1.61 | 354.15 | 449.74 | 0.56 |
| | | | | | | | | |
| 37913.29 | 15 yr | 368.77 | 318 | 319.69 | 2.47 | 153.41 | 175.92 | 0.83 |
| 37913.29 | 25 yr | 418.05 | 318 | 319.77 | 2.55 | 168.13 | 184.55 | 0.84 |
| 37913.29 | 100 yr | 551.8 | 318 | 319.96 | 2.77 | 203.83 | 203.73 | 0.87 |
| | | | | | | | | |
| 37578.99 | 15 yr | 368.77 | 316.16 | 317.93 | 1.46 | 253.37 | 345.61 | 0.55 |
| 37578.99 | 25 yr | 418.05 | 316.16 | 318 | 1.5 | 278.18 | 364.42 | 0.55 |
| 37578.99 | 100 yr | 551.8 | 316.16 | 318.15 | 1.66 | 333.29 | 382.23 | 0.57 |
| | | | | | | | | |
| 37388.5 | 15 yr | 368.77 | 316 | 317.29 | 1.24 | 297.04 | 425.16 | 0.47 |
| 37388.5 | 25 yr | 418.05 | 316 | 317.35 | 1.3 | 322.68 | 437.69 | 0.48 |
| 37388.5 | 100 yr | 551.8 | 316 | 317.5 | 1.4 | 393.3 | 470.5 | 0.49 |
| | | | | | | | | |
| 37116.32 | 15 yr | 368.77 | 313.99 | 316.22 | 1.58 | 246.15 | 375.1 | 0.59 |
| 37116.32 | 25 yr | 418.05 | 313.99 | 316.28 | 1.62 | 272.32 | 387.55 | 0.59 |
| 37116.32 | 100 yr | 551.8 | 313.99 | 316.5 | 1.57 | 363.99 | 487.83 | 0.57 |
| | | | | | | | | |
| 36860.71 | 15 yr | 368.77 | 313 | 314.47 | 2.34 | 157.42 | 184.09 | 0.81 |
| 36860.71 | 25 yr | 418.05 | 313 | 314.56 | 2.4 | 173.98 | 194.85 | 0.81 |
| 36860.71 | 100 yr | 551.8 | 313 | 314.75 | 2.6 | 212.55 | 216.1 | 0.84 |
| | | | | | | | | |
| 36312.92 | 15 yr | 368.77 | 310 | 311.6 | 1.35 | 272.45 | 411.92 | 0.53 |
| 36312.92 | 25 yr | 418.05 | 310 | 311.65 | 1.42 | 293.44 | 418.84 | 0.54 |
| 36312.92 | 100 yr | 551.8 | 310 | 311.78 | 1.58 | 349.96 | 436.94 | 0.56 |
| | | | | | | | | |
| 35825.31 | 15 yr | 368.77 | 307 | 307.99 | 1.96 | 187.94 | 496.93 | 1.02 |
| 35825.31 | 25 yr | 418.05 | 307 | 308.04 | 1.99 | 209.88 | 525.2 | 1.01 |
| 35825.31 | 100 yr | 551.8 | 307 | 308.13 | 2.14 | 258.27 | 573.6 | 1.02 |
| | | | | | | | | |
| 35522.46 | 15 yr | 368.77 | 303.52 | 305.49 | 1.13 | 327.53 | 413.23 | 0.4 |
| 35522.46 | 25 yr | 418.05 | 303.52 | 305.6 | 1.1 | 380.37 | 506.65 | 0.4 |
| 35522.46 | 100 yr | 551.8 | 303.52 | 305.79 | 1.12 | 491.97 | 681.2 | 0.42 |
| | | | | | | | | |
| 35174.5 | 15 yr | 368.77 | 302 | 303.73 | 2.01 | 183.12 | 451.72 | 1.01 |
| 35174.5 | 25 yr | 418.05 | 302 | 303.77 | 2.04 | 204.53 | 519.49 | 1.04 |
| 35174.5 | 100 yr | 551.8 | 302 | 303.87 | 2.19 | 252.34 | 535.78 | 1.02 |
| | | | | | | | | |
| 34699.74 | 15 yr | 368.77 | 299 | 300.67 | 1.23 | 299.16 | 345.57 | 0.42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 34699.74 | 25 yr | 418.05 | 299 | 300.75 | 1.28 | 327.53 | 355.84 | 0.42 |
| 34699.74 | 100 yr | 551.8 | 299 | 300.94 | 1.38 | 398.42 | 380.3 | 0.43 |
| | | | | | | | | |
| 34189.58 | 15 yr | 368.77 | 296.66 | 299.36 | 1.28 | 297.23 | 432.23 | 0.47 |
| 34189.58 | 25 yr | 418.05 | 296.66 | 299.41 | 1.36 | 319.13 | 446.12 | 0.49 |
| 34189.58 | 100 yr | 551.8 | 296.66 | 299.54 | 1.53 | 377.23 | 480.92 | 0.52 |
| | | | | | | | | |
| 33766.21 | 15 yr | 368.77 | 296 | 297.56 | 1.45 | 253.66 | 506.51 | 0.66 |
| 33766.21 | 25 yr | 418.05 | 296 | 297.63 | 1.44 | 289.76 | 547.97 | 0.63 |
| 33766.21 | 100 yr | 551.8 | 296 | 297.81 | 1.39 | 398.1 | 708.96 | 0.59 |
| | | | | | | | | |
| 33481.3 | 15 yr | 368.77 | 295 | 297.23 | 0.6 | 610.58 | 739.88 | 0.21 |
| 33481.3 | 25 yr | 418.05 | 295 | 297.31 | 0.63 | 665.27 | 763.07 | 0.21 |
| 33481.3 | 100 yr | 551.8 | 295 | 297.48 | 0.68 | 806.74 | 820.02 | 0.22 |
| | | | | | | | | |
| 32988.04 | 15 yr | 664.23 | 294.94 | 295.74 | 2.31 | 290.16 | 554.12 | 1 |
| 32988.04 | 25 yr | 757.38 | 294.94 | 295.79 | 2.39 | 319.94 | 569.01 | 1 |
| 32988.04 | 100 yr | 1010.16 | 294.94 | 295.94 | 2.54 | 404.27 | 640.58 | 1 |
| | | | | | | | | |
| 32505.46 | 15 yr | 664.23 | 292.47 | 294.07 | 0.99 | 668.2 | 858.63 | 0.36 |
| 32505.46 | 25 yr | 757.38 | 292.47 | 294.15 | 1.04 | 731.04 | 871.93 | 0.36 |
| 32505.46 | 100 yr | 1010.16 | 292.47 | 294.32 | 1.14 | 886.13 | 910.82 | 0.37 |
| | | | | | | | | |
| 32250.15 | 15 yr | 664.23 | 291.99 | 293.61 | 1.06 | 625.6 | 785.56 | 0.38 |
| 32250.15 | 25 yr | 757.38 | 291.99 | 293.68 | 1.11 | 680 | 812.85 | 0.39 |
| 32250.15 | 100 yr | 1010.16 | 291.99 | 293.85 | 1.23 | 818.97 | 878.72 | 0.41 |
| | | | | | | | | |
| 31930.75 | 15 yr | 664.23 | 291 | 292.09 | 2.08 | 319.64 | 766.7 | 1.03 |
| 31930.75 | 25 yr | 757.38 | 291 | 292.13 | 2.15 | 352.82 | 773.7 | 1.01 |
| 31930.75 | 100 yr | 1010.16 | 291 | 292.24 | 2.33 | 433.91 | 789.59 | 1 |
| | | | | | | | | |
| 31398.58 | 15 yr | 664.23 | 287 | 289.44 | 1.15 | 578.67 | 792.4 | 0.43 |
| 31398.58 | 25 yr | 757.38 | 287 | 289.56 | 1.13 | 672.43 | 834.57 | 0.4 |
| 31398.58 | 100 yr | 1010.16 | 287 | 289.76 | 1.19 | 846.65 | 865.46 | 0.39 |
| | | | | | | | | |
| 31119.54 | 15 yr | 664.23 | 286.48 | 288.66 | 1.5 | 436.14 | 424.23 | 0.48 |
| 31119.54 | 25 yr | 757.38 | 286.48 | 288.82 | 1.43 | 515.99 | 560.08 | 0.49 |
| 31119.54 | 100 yr | 1010.16 | 286.48 | 289.14 | 1.24 | 794.13 | 1040.63 | 0.45 |
| | | | | | | | | |
| 30897.71 | 15 yr | 664.23 | 286 | 287.68 | 2.08 | 321.18 | 354.25 | 0.7 |
| 30897.71 | 25 yr | 757.38 | 286 | 287.74 | 2.22 | 342.49 | 363.1 | 0.73 |
| 30897.71 | 100 yr | 1010.16 | 286 | 288.05 | 2.07 | 484.22 | 657.18 | 0.78 |
| | | | | | | | | |
| 30435.88 | 15 yr | 664.23 | 283.29 | 284.11 | 1.01 | 320.46 | 520.25 | 0.64 |
| 30435.88 | 25 yr | 757.38 | 283.29 | 284.2 | 1.19 | 369 | 532.24 | 0.64 |
| 30435.88 | 100 yr | 1010.16 | 283.29 | 284.42 | 1.5 | 485.98 | 561.09 | 0.65 |
| | | | | | | | | |
| 30065.69 | 15 yr | 703.63 | 280.08 | 282.94 | 1.48 | 503.8 | 464.39 | 0.44 |
| 30065.69 | 25 yr | 802.72 | 280.08 | 283.05 | 1.53 | 558.21 | 488.93 | 0.45 |
| 30065.69 | 100 yr | 1071.65 | 280.08 | 283.31 | 1.67 | 690.63 | 533.77 | 0.45 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 29424.37 | 15 yr | 703.63 | 279.94 | 281.31 | 1.18 | 410.64 | 438.77 | 0.51 |
| 29424.37 | 25 yr | 802.72 | 279.94 | 281.39 | 1.24 | 450.09 | 467.47 | 0.52 |
| 29424.37 | 100 yr | 1071.65 | 279.94 | 281.6 | 1.39 | 551.26 | 534.07 | 0.55 |
| | | | | | | | | |
| 28946.19 | 15 yr | 703.63 | 278 | 279.92 | 1.29 | 550.11 | 654.35 | 0.46 |
| 28946.19 | 25 yr | 802.72 | 278 | 279.99 | 1.36 | 596.03 | 655.43 | 0.47 |
| 28946.19 | 100 yr | 1071.65 | 278 | 280.17 | 1.52 | 713.78 | 658.29 | 0.48 |
| | | | | | | | | |
| 28498.95 | 15 yr | 703.63 | 277 | 277.64 | 1.37 | 327.69 | 523.3 | 0.72 |
| 28498.95 | 25 yr | 802.72 | 277 | 277.72 | 1.51 | 367.03 | 560.94 | 0.74 |
| 28498.95 | 100 yr | 1071.65 | 277 | 277.86 | 1.89 | 449.15 | 600.21 | 0.81 |
| | | | | | | | | |
| 28235.97 | 15 yr | 703.63 | 276.74 | 277.23 | 0.27 | 944.63 | 770.84 | 0.14 |
| 28235.97 | 25 yr | 802.72 | 276.74 | 277.51 | 0.35 | 1160.61 | 772.09 | 0.14 |
| 28235.97 | 100 yr | 1071.65 | 276.74 | 277.72 | 0.47 | 1318.83 | 773.05 | 0.17 |
| | | | | | | | | |
| 27849.92 | 15 yr | 703.63 | 272.56 | 277.16 | 0.44 | 1389.58 | 745.02 | 0.11 |
| 27849.92 | 25 yr | 802.72 | 272.56 | 277.45 | 0.43 | 1615.95 | 803.42 | 0.11 |
| 27849.92 | 100 yr | 1071.65 | 272.56 | 277.64 | 0.54 | 1765.81 | 820.94 | 0.13 |
| | | | | | | | | |
| 27389.82 | 15 yr | 703.63 | 275.12 | 275.82 | 1.53 | 154.88 | 75.77 | 0.82 |
| 27389.82 | 25 yr | 802.72 | 275.12 | 275.99 | 1.79 | 167.94 | 78.88 | 0.87 |
| 27389.82 | 100 yr | 1071.65 | 275.12 | 277.04 | 1.16 | 506.55 | 553.69 | 0.49 |
| | | | | | | | | |
| 27166.32 | 15 yr | 703.63 | 275.58 | 275.41 | | 331.17 | 149.88 | 0 |
| 27166.32 | 25 yr | 802.72 | 275.58 | 275.54 | | 350.01 | 152.32 | 0 |
| 27166.32 | 100 yr | 1071.65 | 275.58 | 275.84 | 0.46 | 399.52 | 173.49 | 0.39 |
| | | | | | | | | |
| 26909.88 | 15 yr | 703.63 | 273.85 | 274.56 | 1.2 | 333.34 | 384.33 | 0.58 |
| 26909.88 | 25 yr | 802.72 | 273.85 | 274.65 | 1.32 | 368.29 | 402.6 | 0.59 |
| 26909.88 | 100 yr | 1071.65 | 273.85 | 274.85 | 1.48 | 457.03 | 488.63 | 0.63 |
| 26729.79 | 15 yr | 703.63 | 272.5 | 273.37 | 2.04 | 313.38 | 535.68 | 0.92 |
| 26729.79 | 25 yr | 802.72 | 272.5 | 273.42 | 2.17 | 339.56 | 544.88 | 0.95 |
| 26729.79 | 100 yr | 1071.65 | 272.5 | 273.55 | 2.41 | 416.71 | 571.13 | 0.96 |
| | | | | | | | | |
| 26351.97 | 15 yr | 703.63 | 269 | 271.25 | 1.3 | 588.67 | 573.59 | 0.37 |
| 26351.97 | 25 yr | 802.72 | 269 | 271.35 | 1.35 | 645.25 | 592.68 | 0.38 |
| 26351.97 | 100 yr | 1071.65 | 269 | 271.58 | 1.48 | 789.09 | 676.81 | 0.4 |
| | | | | | | | | |
| 26017.88 | 15 yr | 703.63 | 269 | 270.61 | 1.39 | 529.81 | 640.93 | 0.45 |
| 26017.88 | 25 yr | 802.72 | 269 | 270.7 | 1.44 | 591.73 | 698.72 | 0.45 |
| 26017.88 | 100 yr | 1071.65 | 269 | 270.92 | 1.54 | 754.18 | 766.04 | 0.45 |
| | | | | | | | | |
| 25739.67 | 15 yr | 703.63 | 268 | 269.66 | 1.88 | 401.52 | 433.75 | 0.61 |
| 25739.67 | 25 yr | 802.72 | 268 | 269.74 | 1.99 | 434.38 | 444.71 | 0.63 |
| 25739.67 | 100 yr | 1071.65 | 268 | 269.91 | 2.25 | 514.84 | 470.47 | 0.67 |
| | | | | | | | | |
| 25410.86 | 15 yr | 703.63 | 266 | 267.77 | 1.91 | 369.92 | 539.19 | 0.74 |
| 25410.86 | 25 yr | 802.72 | 266 | 267.83 | 2 | 405.72 | 551.17 | 0.74 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 25410.86 | 100 yr | 1071.65 | 266 | 268 | 2.21 | 500.21 | 581.46 | 0.74 |
| | | | | | | | | |
| 24978.42 | 15 yr | 827.54 | 264.4 | 266.57 | 1.12 | 773.77 | 854.69 | 0.37 |
| 24978.42 | 25 yr | 945.45 | 264.4 | 266.65 | 1.17 | 842.47 | 867.63 | 0.38 |
| 24978.42 | 100 yr | 1265.45 | 264.4 | 266.85 | 1.28 | 1018.56 | 909.09 | 0.39 |
| | | | | | | | | |
| 24500.53 | 15 yr | 827.54 | 263 | 265.83 | 1.08 | 792.69 | 957.01 | 0.38 |
| 24500.53 | 25 yr | 945.45 | 263 | 265.9 | 1.12 | 861.55 | 979.69 | 0.39 |
| 24500.53 | 100 yr | 1265.45 | 263 | 266.08 | 1.19 | 1048.53 | 1077.5 | 0.41 |
| | | | | | | | | |
| 24227.6 | 15 yr | 827.54 | 262 | 265.22 | 1.15 | 758.8 | 1057.12 | 0.43 |
| 24227.6 | 25 yr | 945.45 | 262 | 265.28 | 1.22 | 823.96 | 1058.06 | 0.43 |
| 24227.6 | 100 yr | 1265.45 | 262 | 265.43 | 1.38 | 976.54 | 1058.81 | 0.45 |
| | | | | | | | | |
| 23834.48 | 15 yr | 827.54 | 261 | 263.04 | 2.49 | 331.6 | 534.8 | 1.01 |
| 23834.48 | 25 yr | 945.45 | 261 | 263.11 | 2.56 | 369.15 | 556.27 | 1.01 |
| 23834.48 | 100 yr | 1265.45 | 261 | 263.34 | 2.41 | 539.05 | 980.53 | 0.95 |
| | | | | | | | | |
| 23449.39 | 15 yr | 827.54 | 260 | 262.61 | 0.73 | 1178.7 | 1202.29 | 0.21 |
| 23449.39 | 25 yr | 945.45 | 260 | 262.7 | 0.78 | 1278.79 | 1218.12 | 0.22 |
| 23449.39 | 100 yr | 1265.45 | 260 | 262.9 | 0.88 | 1521.87 | 1225.54 | 0.23 |
| | | | | | | | | |
| 23238.46 | 15 yr | 827.54 | 260 | 262.42 | 1.01 | 821.73 | 833.15 | 0.32 |
| 23238.46 | 25 yr | 945.45 | 260 | 262.5 | 1.07 | 882.01 | 835.34 | 0.33 |
| 23238.46 | 100 yr | 1265.45 | 260 | 262.67 | 1.23 | 1029.17 | 840.67 | 0.35 |
| | | | | | | | | |
| 23065.81 | 15 yr | 827.54 | 260 | 261.93 | 1.61 | 511.55 | 802.87 | 0.65 |
| 23065.81 | 25 yr | 945.45 | 260 | 261.98 | 1.7 | 554.8 | 804.31 | 0.66 |
| 23065.81 | 100 yr | 1265.45 | 260 | 262.12 | 1.9 | 665.82 | 808 | 0.67 |
| | | | | | | | | |
| 22734.73 | 15 yr | 827.54 | 258 | 260.33 | 1.59 | 522.05 | 631.08 | 0.56 |
| 22734.73 | 25 yr | 945.45 | 258 | 260.41 | 1.66 | 573.55 | 641.75 | 0.56 |
| 22734.73 | 100 yr | 1265.45 | 258 | 260.61 | 1.8 | 705.05 | 668.19 | 0.56 |
| | | | | | | | | |
| 22394.96 | 15 yr | 878.82 | 257 | 259.15 | 1.65 | 549.42 | 567.55 | 0.51 |
| 22394.96 | 25 yr | 1004.56 | 257 | 259.23 | 1.74 | 597.04 | 579.08 | 0.52 |
| 22394.96 | 100 yr | 1345.82 | 257 | 259.45 | 1.95 | 723.19 | 608.56 | 0.53 |
| | | | | | | | | |
| 22006.9 | 15 yr | 878.82 | 256 | 256.99 | 2.21 | 397.71 | 641.35 | 0.9 |
| 22006.9 | 25 yr | 1004.56 | 256 | 257.04 | 2.31 | 435.56 | 658.64 | 0.91 |
| 22006.9 | 100 yr | 1345.82 | 256 | 257.17 | 2.59 | 518.86 | 689.73 | 0.95 |
| | | | | | | | | |
| 21653.21 | 15 yr | 878.82 | 253.76 | 255.05 | 1.5 | 585.4 | 693.36 | 0.52 |
| 21653.21 | 25 yr | 1004.56 | 253.76 | 255.14 | 1.54 | 651.36 | 749.95 | 0.52 |
| 21653.21 | 100 yr | 1345.82 | 253.76 | 255.34 | 1.67 | 809.62 | 789.73 | 0.52 |
| | | | | | | | | |
| 21453.34 | 15 yr | 878.82 | 252.75 | 254.4 | 1.5 | 598.34 | 635.56 | 0.49 |
| 21453.34 | 25 yr | 1004.56 | 252.75 | 254.49 | 1.56 | 657.97 | 661.28 | 0.49 |
| 21453.34 | 100 yr | 1345.82 | 252.75 | 254.7 | 1.71 | 803.86 | 724.51 | 0.51 |
| | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|
| 21179.88 | 15 yr | 878.82 | 250 | 252.64 | 2.67 | 329.06 | 458.38 | 1.01 |
| 21179.88 | 25 yr | 1004.56 | 250 | 252.77 | 2.54 | 397.17 | 621.18 | 1 |
| 21179.88 | 100 yr | 1345.82 | 250 | 252.92 | 2.7 | 502.12 | 711.77 | 1.01 |
| 20844.54 | 15 yr | 878.82 | 249 | 251.49 | 1.17 | 773.24 | 718.81 | 0.34 |
| 20844.54 | 25 yr | 1004.56 | 249 | 251.59 | 1.23 | 845.9 | 799.82 | 0.36 |
| 20844.54 | 100 yr | 1345.82 | 249 | 251.79 | 1.36 | 1027.33 | 945.81 | 0.39 |
| | | | | | | | | |
| 20633.58 | 15 yr | 878.82 | 249 | 251.12 | 1.2 | 734.54 | 940.72 | 0.43 |
| 20633.58 | 25 yr | 1004.56 | 249 | 251.19 | 1.26 | 801.62 | 943.63 | 0.44 |
| 20633.58 | 100 yr | 1345.82 | 249 | 251.34 | 1.43 | 946.2 | 949.87 | 0.46 |
| | | | | | | | | |
| 20149.02 | 15 yr | 916.17 | 245 | 248.35 | 2.33 | 397.43 | 800 | 1.05 |
| 20149.02 | 25 yr | 1047.63 | 245 | 248.39 | 2.49 | 425.82 | 807.54 | 1.09 |
| 20149.02 | 100 yr | 1404.41 | 245 | 248.51 | 2.69 | 527.87 | 820.09 | 1.06 |
| | | | | | | | | |
| 19778.98 | 15 yr | 916.17 | 243.29 | 245.5 | 1.36 | 675.36 | 592.75 | 0.41 |
| 19778.98 | 25 yr | 1047.63 | 243.29 | 245.58 | 1.44 | 727.45 | 594.82 | 0.42 |
| 19778.98 | 100 yr | 1404.41 | 243.29 | 245.8 | 1.64 | 858.27 | 600.06 | 0.44 |
| | | | | | | | | |
| 19367.81 | 15 yr | 916.17 | 242 | 244.05 | 1.85 | 504.72 | 787.91 | 0.73 |
| 19367.81 | 25 yr | 1047.63 | 242 | 244.1 | 1.95 | 546.34 | 793.33 | 0.74 |
| 19367.81 | 100 yr | 1404.41 | 242 | 244.23 | 2.21 | 646.7 | 805.13 | 0.78 |
| | | | | | | | | |
| 19050.14 | 15 yr | 916.17 | 241 | 242.56 | 1.42 | 650.34 | 850.29 | 0.51 |
| 19050.14 | 25 yr | 1047.63 | 241 | 242.64 | 1.46 | 719.21 | 872.31 | 0.51 |
| 19050.14 | 100 yr | 1404.41 | 241 | 242.84 | 1.57 | 898.1 | 927.06 | 0.51 |
| | | | | | | | | |
| 18585.42 | 15 yr | 916.17 | 240 | 241.61 | 1.1 | 823 | 765.18 | 0.34 |
| 18585.42 | 25 yr | 1047.63 | 240 | 241.7 | 1.16 | 891.06 | 765.82 | 0.35 |
| 18585.42 | 100 yr | 1404.41 | 240 | 241.92 | 1.32 | 1058.05 | 767.39 | 0.36 |
| | | | | | | | | |
| 18081.62 | 15 yr | 916.17 | 237.6 | 240.35 | 1.84 | 512.92 | 569.57 | 0.59 |
| 18081.62 | 25 yr | 1047.63 | 237.6 | 240.45 | 1.89 | 571.22 | 583.53 | 0.59 |
| 18081.62 | 100 yr | 1404.41 | 237.6 | 240.68 | 2.06 | 706.32 | 585.69 | 0.58 |
| | | | | | | | | |
| 17552.47 | 15 yr | 916.17 | 236 | 238.47 | 1.8 | 510.26 | 435.72 | 0.52 |
| 17552.47 | 25 yr | 1047.63 | 236 | 238.56 | 1.91 | 551.83 | 447.49 | 0.53 |
| 17552.47 | 100 yr | 1404.41 | 236 | 238.79 | 2.18 | 657.57 | 479.35 | 0.56 |
| | | | | | | | | |
| 17218.29 | 15 yr | 916.17 | 236 | 237.22 | 1.77 | 532.28 | 693.66 | 0.62 |
| 17218.29 | 25 yr | 1047.63 | 236 | 237.28 | 1.87 | 574.96 | 694.26 | 0.63 |
| 17218.29 | 100 yr | 1404.41 | 236 | 237.43 | 2.13 | 678.15 | 695.72 | 0.67 |
| | | | | | | | | |
| 16811.78 | 15 yr | 916.17 | 234 | 236.24 | 1.14 | 816.76 | 842.61 | 0.36 |
| 16811.78 | 25 yr | 1047.63 | 234 | 236.36 | 1.15 | 922 | 866.54 | 0.35 |
| 16811.78 | 100 yr | 1404.41 | 234 | 236.66 | 1.21 | 1182.54 | 874.68 | 0.33 |
| | | | | | | | | |
| 16505.44 | 15 yr | 916.17 | 233.63 | 236.08 | 0.71 | 1316.16 | 884.79 | 0.18 |
| 16505.44 | 25 yr | 1047.63 | 233.63 | 236.21 | 0.75 | 1427.69 | 886.8 | 0.18 |
| 16505.44 | 100 yr | 1404.41 | 233.63 | 236.52 | 0.85 | 1700.09 | 891.37 | 0.19 |

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|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 16070.23 | 15 yr | 916.17 | 233 | 235.66 | 1.64 | 560.95 | 491.84 | 0.48 |
| 16070.23 | 25 yr | 1047.63 | 233 | 235.78 | 1.7 | 619.09 | 508.57 | 0.48 |
| 16070.23 | 100 yr | 1404.41 | 233 | 236.06 | 1.85 | 767.62 | 534.99 | 0.48 |
| | | | | | | | | |
| 15691.2 | 15 yr | 916.17 | 230.06 | 234.72 | 1.74 | 525.63 | 367.1 | 0.46 |
| 15691.2 | 25 yr | 1047.63 | 230.06 | 234.84 | 1.84 | 571.47 | 388.52 | 0.46 |
| 15691.2 | 100 yr | 1404.41 | 230.06 | 235.13 | 2.07 | 693.31 | 435.77 | 0.48 |
| | | | | | | | | |
| 15223.25 | 15 yr | 1013.22 | 229 | 233.61 | 1.82 | 558.02 | 392.16 | 0.48 |
| 15223.25 | 25 yr | 1159.6 | 229 | 233.74 | 1.91 | 611.43 | 405.67 | 0.48 |
| 15223.25 | 100 yr | 1538.46 | 229 | 234.04 | 2.12 | 737.55 | 431.95 | 0.49 |
| | | | | | | | | |
| 14902.12 | 15 yr | 1013.22 | 230 | 232.27 | 2.52 | 410.33 | 322.88 | 0.73 |
| 14902.12 | 25 yr | 1159.6 | 230 | 232.4 | 2.57 | 453.15 | 347.96 | 0.74 |
| 14902.12 | 100 yr | 1538.46 | 230 | 232.68 | 2.68 | 558.59 | 403.12 | 0.76 |
| | | | | | | | | |
| 14613.2 | 15 yr | 1013.22 | 229 | 231.43 | 1.54 | 682.84 | 548.86 | 0.44 |
| 14613.2 | 25 yr | 1159.6 | 229 | 231.53 | 1.62 | 738.88 | 558.42 | 0.45 |
| 14613.2 | 100 yr | 1538.46 | 229 | 231.76 | 1.81 | 872.73 | 580.61 | 0.47 |
| | | | | | | | | |
| 14298.47 | 15 yr | 1013.22 | 228 | 230.53 | 1.86 | 623.37 | 724.9 | 0.56 |
| 14298.47 | 25 yr | 1159.6 | 228 | 230.61 | 1.95 | 684.07 | 740.19 | 0.57 |
| 14298.47 | 100 yr | 1538.46 | 228 | 230.78 | 2.2 | 814.08 | 769.33 | 0.6 |
| | | | | | | | | |
| 13901.36 | 15 yr | 1013.22 | 226 | 227.7 | 2.49 | 418.9 | 716.57 | 1.06 |
| 13901.36 | 25 yr | 1159.6 | 226 | 227.76 | 2.61 | 457.3 | 755.48 | 1.08 |
| 13901.36 | 100 yr | 1538.46 | 226 | 227.9 | 2.87 | 567.39 | 780.76 | 1.07 |
| | | | | | | | | |
| 13541.06 | 15 yr | 1013.22 | 224 | 225.98 | 1.43 | 726.5 | 564.66 | 0.39 |
| 13541.06 | 25 yr | 1159.6 | 224 | 226.13 | 1.48 | 825.71 | 750.98 | 0.4 |
| 13541.06 | 100 yr | 1538.46 | 224 | 226.41 | 1.58 | 1053.47 | 878.21 | 0.41 |
| | | | | | | | | |
| 13261.25 | 15 yr | 1013.22 | 224 | 225.56 | 1.37 | 789.98 | 642.69 | 0.36 |
| 13261.25 | 25 yr | 1159.6 | 224 | 225.76 | 1.36 | 919.38 | 655.16 | 0.34 |
| 13261.25 | 100 yr | 1538.46 | 224 | 225.99 | 1.54 | 1074.73 | 701.41 | 0.36 |
| | | | | | | | | |
| 12637.49 | 15 yr | 1013.22 | 221 | 223.82 | 2.78 | 364.83 | 196.32 | 0.65 |
| 12637.49 | 25 yr | 1159.6 | 221 | 224.1 | 2.65 | 459.61 | 531.12 | 0.71 |
| 12637.49 | 100 yr | 1538.46 | 221 | 224.49 | 2.57 | 683.28 | 593.3 | 0.61 |
| | | | | | | | | |
| 12020.78 | 15 yr | 1013.22 | 220 | 223.21 | 1.24 | 836.1 | 403.61 | 0.27 |
| 12020.78 | 25 yr | 1159.6 | 220 | 223.37 | 1.32 | 900.35 | 408.72 | 0.27 |
| 12020.78 | 100 yr | 1538.46 | 220 | 223.71 | 1.53 | 1039.91 | 421.98 | 0.3 |
| | | | | | | | | |
| 11488.94 | 15 yr | 1013.22 | 219 | 221.8 | 3.22 | 314.43 | 300.5 | 1.01 |
| 11488.94 | 25 yr | 1159.6 | 219 | 221.93 | 3.27 | 354.61 | 327.71 | 1 |
| 11488.94 | 100 yr | 1538.46 | 219 | 222.22 | 3.36 | 471.16 | 477.41 | 0.94 |
| | | | | | | | | |
| 11165.76 | 15 yr | 1013.22 | 217 | 221 | 1.57 | 685.01 | 575.82 | 0.39 |

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|---|---|---|---|---|---|---|---|---|
| 11165.76 | 25 yr | 1159.6 | 217 | 221.14 | 1.63 | 763.34 | 575.82 | 0.39 |
| 11165.76 | 100 yr | 1538.46 | 217 | 221.43 | 1.8 | 933.26 | 575.82 | 0.4 |
| | | | | | | | | |
| 10821.46 | 15 yr | 1013.22 | 217 | 219.36 | 3.45 | 293.96 | 240.82 | 1 |
| 10821.46 | 25 yr | 1159.6 | 217 | 219.55 | 3.34 | 347.16 | 308.82 | 1.01 |
| 10821.46 | 100 yr | 1538.46 | 217 | 219.83 | 3.47 | 443.55 | 365.62 | 1 |
| | | | | | | | | |
| 10556.85 | 15 yr | 1013.22 | 216 | 218.74 | 1.43 | 708.65 | 406.1 | 0.35 |
| 10556.85 | 25 yr | 1159.6 | 216 | 218.87 | 1.52 | 764.04 | 412.77 | 0.36 |
| 10556.85 | 100 yr | 1538.46 | 216 | 219.2 | 1.7 | 904.2 | 453.26 | 0.38 |
| | | | | | | | | |
| 10440.54 | 15 yr | 1013.22 | 216 | 218.54 | 1.61 | 634.41 | 419.47 | 0.4 |
| 10440.54 | 25 yr | 1159.6 | 216 | 218.67 | 1.71 | 688.32 | 426.23 | 0.41 |
| 10440.54 | 100 yr | 1538.46 | 216 | 218.98 | 1.91 | 821.15 | 442.46 | 0.43 |
| | | | | | | | | |
| 10105.02 | 15 yr | 1013.22 | 215 | 217.34 | 2.33 | 442.04 | 514.89 | 0.79 |
| 10105.02 | 25 yr | 1159.6 | 215 | 217.39 | 2.53 | 466.69 | 517.8 | 0.84 |
| 10105.02 | 100 yr | 1538.46 | 215 | 217.49 | 3.01 | 521.98 | 530.98 | 0.95 |
| | | | | | | | | |
| 9800.565 | 15 yr | 1013.22 | 213.07 | 214.61 | 2.45 | 425.87 | 579.39 | 0.88 |
| 9800.565 | 25 yr | 1159.6 | 213.07 | 214.7 | 2.5 | 479.74 | 586.58 | 0.85 |
| 9800.565 | 100 yr | 1538.46 | 213.07 | 214.93 | 2.6 | 616.56 | 603.02 | 0.79 |
| | | | | | | | | |
| 9238.513 | 15 yr | 1013.22 | 208.33 | 210.61 | 2.5 | 431.64 | 391.02 | 0.69 |
| 9238.513 | 25 yr | 1159.6 | 208.33 | 210.69 | 2.68 | 464.73 | 404.58 | 0.73 |
| 9238.513 | 100 yr | 1538.46 | 208.33 | 210.86 | 3.1 | 539.68 | 491.27 | 0.81 |
| | | | | | | | | |
| 8722.187 | 15 yr | 1013.22 | 205.89 | 208.04 | 2.3 | 453 | 549.02 | 0.65 |
| 8722.187 | 25 yr | 1159.6 | 205.89 | 208.17 | 2.34 | 531.57 | 637.59 | 0.64 |
| 8722.187 | 100 yr | 1538.46 | 205.89 | 208.47 | 2.41 | 741.82 | 785.22 | 0.6 |
| | | | | | | | | |
| 8287.262 | 15 yr | 1013.22 | 203.64 | 206.07 | 2.17 | 469.07 | 383.45 | 0.63 |
| 8287.262 | 25 yr | 1159.6 | 203.64 | 206.14 | 2.35 | 494.69 | 391.86 | 0.67 |
| 8287.262 | 100 yr | 1538.46 | 203.64 | 206.32 | 2.72 | 567.22 | 423.71 | 0.75 |
| | | | | | | | | |
| 7952.195 | 15 yr | 1013.22 | 203.07 | 204.98 | 1.62 | 656.44 | 649.49 | 0.49 |
| 7952.195 | 25 yr | 1159.6 | 203.07 | 205.14 | 1.62 | 754.6 | 654.29 | 0.46 |
| 7952.195 | 100 yr | 1538.46 | 203.07 | 205.49 | 1.64 | 990.22 | 665.66 | 0.41 |
| | | | | | | | | |
| 7478.377 | 15 yr | 1013.22 | 201.51 | 204.38 | 1.3 | 816.01 | 406.92 | 0.29 |
| 7478.377 | 25 yr | 1159.6 | 201.51 | 204.57 | 1.35 | 896.14 | 407.23 | 0.29 |
| 7478.377 | 100 yr | 1538.46 | 201.51 | 204.97 | 1.52 | 1059.63 | 407.85 | 0.3 |
| | | | | | | | | |
| 7236.212 | 15 yr | 1013.22 | 201 | 203.98 | 1.95 | 541.95 | 282.95 | 0.44 |
| 7236.212 | 25 yr | 1159.6 | 201 | 204.17 | 2.06 | 597.04 | 283.85 | 0.45 |
| 7236.212 | 100 yr | 1538.46 | 201 | 204.53 | 2.34 | 697.95 | 284.32 | 0.47 |
| | | | | | | | | |
| 6821.413 | 15 yr | 1013.22 | 199 | 202.7 | 2.47 | 419.69 | 296.65 | 0.67 |
| 6821.413 | 25 yr | 1159.6 | 199 | 202.83 | 2.5 | 461.38 | 344.16 | 0.71 |
| 6821.413 | 100 yr | 1538.46 | 199 | 203.09 | 2.69 | 559.78 | 398.88 | 0.75 |

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|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 6655.992 | 15 yr | 1013.22 | 199 | 202.05 | 1.83 | 557.37 | 524 | 0.59 |
| 6655.992 | 25 yr | 1159.6 | 199 | 202.16 | 1.91 | 613.38 | 524 | 0.58 |
| 6655.992 | 100 yr | 1538.46 | 199 | 202.33 | 2.23 | 703.49 | 524 | 0.63 |
| | | | | | | | | |
| 6453.78 | 15 yr | 1013.22 | 197.9 | 201.15 | 1.96 | 589.37 | 697.16 | 0.62 |
| 6453.78 | 25 yr | 1159.6 | 197.9 | 201.28 | 1.81 | 685.18 | 817.44 | 0.62 |
| 6453.78 | 100 yr | 1538.46 | 197.9 | 201.46 | 1.97 | 836.81 | 819.16 | 0.61 |
| | | | | | | | | |
| 6267.543 | 15 yr | 1139.65 | 197.27 | 199.68 | 2.84 | 463.72 | 649.6 | 0.92 |
| 6267.543 | 25 yr | 1305.57 | 197.27 | 199.76 | 2.91 | 519.77 | 660.46 | 0.91 |
| 6267.543 | 100 yr | 1755.85 | 197.27 | 199.93 | 3.21 | 631.29 | 681.55 | 0.94 |
| | | | | | | | | |
| 5796.243 | 15 yr | 1139.65 | 195 | 197.56 | 1.39 | 829.57 | 811.07 | 0.44 |
| 5796.243 | 25 yr | 1305.57 | 195 | 197.64 | 1.47 | 896.71 | 828.49 | 0.45 |
| 5796.243 | 100 yr | 1755.85 | 195 | 197.85 | 1.67 | 1070.11 | 867.18 | 0.46 |
| | | | | | | | | |
| 5373.074 | 15 yr | 1139.65 | 193 | 195.33 | 2.71 | 430.72 | 608.93 | 1 |
| 5373.074 | 25 yr | 1305.57 | 193 | 195.41 | 2.8 | 481.18 | 620.93 | 0.98 |
| 5373.074 | 100 yr | 1755.85 | 193 | 195.6 | 3.06 | 599.67 | 638.03 | 0.97 |
| | | | | | | | | |
| 4869.663 | 15 yr | 1139.65 | 191 | 193.43 | 1.39 | 877.6 | 685.94 | 0.39 |
| 4869.663 | 25 yr | 1305.57 | 191 | 193.54 | 1.44 | 957.09 | 703.94 | 0.4 |
| 4869.663 | 100 yr | 1755.85 | 191 | 193.84 | 1.52 | 1171.97 | 756.53 | 0.4 |
| | | | | | | | | |
| 4260.318 | 15 yr | 1139.65 | 189 | 192.31 | 1.78 | 764.82 | 603.6 | 0.44 |
| 4260.318 | 25 yr | 1305.57 | 189 | 192.46 | 1.82 | 854.31 | 603.6 | 0.43 |
| 4260.318 | 100 yr | 1755.85 | 189 | 192.82 | 1.93 | 1069.04 | 603.6 | 0.42 |
| | | | | | | | | |
| 3725.853 | 15 yr | 1139.65 | 188.03 | 191.8 | 1.34 | 977.02 | 526.75 | 0.27 |
| 3725.853 | 25 yr | 1305.57 | 188.03 | 191.94 | 1.43 | 1052.27 | 526.92 | 0.28 |
| 3725.853 | 100 yr | 1755.85 | 188.03 | 192.28 | 1.65 | 1229.26 | 527.3 | 0.3 |
| | | | | | | | | |
| 3258.062 | 15 yr | 1139.65 | 187 | 190.74 | 2.72 | 422.99 | 445.66 | 0.86 |
| 3258.062 | 25 yr | 1305.57 | 187 | 190.85 | 2.78 | 477.45 | 500 | 0.85 |
| 3258.062 | 100 yr | 1755.85 | 187 | 191.09 | 3.03 | 604.07 | 560.78 | 0.84 |
| | | | | | | | | |
| 2911.651 | 15 yr | 1139.65 | 186 | 189.12 | 1.98 | 586.58 | 460.16 | 0.55 |
| 2911.651 | 25 yr | 1305.57 | 186 | 189.25 | 2.06 | 647.01 | 482.53 | 0.55 |
| 2911.651 | 100 yr | 1755.85 | 186 | 189.56 | 2.24 | 807.01 | 539.15 | 0.57 |
| | | | | | | | | |
| 2611.226 | 15 yr | 1195.47 | 186 | 188.68 | 1.27 | 950.78 | 626.54 | 0.33 |
| 2611.226 | 25 yr | 1370.05 | 186 | 188.8 | 1.34 | 1030.5 | 640.08 | 0.33 |
| 2611.226 | 100 yr | 1843.83 | 186 | 189.11 | 1.52 | 1234.49 | 670.32 | 0.35 |
| | | | | | | | | |
| 1989.699 | 15 yr | 1195.47 | 185 | 187.3 | 2.04 | 587.48 | 547.37 | 0.62 |
| 1989.699 | 25 yr | 1370.05 | 185 | 187.39 | 2.15 | 639.47 | 555.14 | 0.63 |
| 1989.699 | 100 yr | 1843.83 | 185 | 187.59 | 2.46 | 754.09 | 571.9 | 0.68 |
| | | | | | | | | |
| 1577.247 | 15 yr | 1195.47 | 182 | 184.01 | 3.18 | 373.92 | 362.8 | 1.02 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1577.247 | 25 yr | 1370.05 | 182 | 184.11 | 3.32 | 411.59 | 364.66 | 1.02 |
| 1577.247 | 100 yr | 1843.83 | 182 | 184.42 | 3.51 | 526.33 | 370.27 | 0.95 |
| | | | | | | | | |
| 1284.676 | 15 yr | 1195.47 | 180 | 182.51 | 2.29 | 525.96 | 320.4 | 0.56 |
| 1284.676 | 25 yr | 1370.05 | 180 | 182.63 | 2.44 | 565.58 | 322.75 | 0.58 |
| 1284.676 | 100 yr | 1843.83 | 180 | 182.91 | 2.84 | 655.36 | 328.01 | 0.63 |
| | | | | | | | | |
| 940.398 | 15 yr | 1195.47 | 179 | 180.47 | 2.86 | 460.04 | 614.75 | 0.99 |
| 940.398 | 25 yr | 1370.05 | 179 | 180.53 | 3.01 | 499.71 | 617.83 | 1 |
| 940.398 | 100 yr | 1843.83 | 179 | 180.71 | 3.31 | 611.58 | 626.44 | 1.01 |
| | | | | | | | | |
| 643.571 | 15 yr | 1213.43 | 177 | 179.72 | 1.19 | 1007.57 | 816.16 | 0.35 |
| 643.571 | 25 yr | 1390.8 | 177 | 179.89 | 1.22 | 1144.63 | 828.68 | 0.33 |
| 643.571 | 100 yr | 1872.17 | 177 | 180.25 | 1.33 | 1447.23 | 855.68 | 0.32 |
| | | | | | | | | |
| 382.416 | 15 yr | 1213.43 | 175.95 | 178.41 | 3.53 | 348.55 | 210.95 | 0.87 |
| 382.416 | 25 yr | 1390.8 | 175.95 | 178.54 | 3.75 | 376.11 | 217.04 | 0.9 |
| 382.416 | 100 yr | 1872.17 | 175.95 | 179.07 | 3.51 | 573.74 | 577.53 | 0.89 |
| | | | | | | | | |
| 42.715 | 15 yr | 1213.43 | 172.98 | 175.54 | 3.27 | 398.39 | 417.29 | 0.94 |
| 42.715 | 25 yr | 1390.8 | 172.98 | 175.65 | 3.4 | 443.11 | 426.47 | 0.94 |
| 42.715 | 100 yr | 1872.17 | 172.98 | 175.85 | 3.87 | 534.3 | 444.61 | 0.99 |