CHAPTER V
FLOOD MORPHOLOGY

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CHAPTER 5

FLOOD MORPHOLOGY

5.1 Introduction:

In many parts of the world, floods that invade river plains and coastal low lands are very serious natural hazards. Flood prone low areas are often densely populated and form the economic main stay of numerous countries. Flood events are a part of nature, which have existed and will continue to exist. The causes of flood are diversified and vary with the river basin or the region. Local rains following in the flood susceptible areas and their immediate surroundings area are first factors. Although floods are natural phenomena, human activities and human interventions into the processes of nature, such as alterations in the drainage patterns from urbanization, agricultural practices and deforestation, have considerably changed the situation in whole river basins. At the same time, exposition to risk and vulnerability in flood-prone area has been growing constantly. Therefore, to find out the frequency and magnitude as well as for management and precaution of future floods, the study of flood geomorphology is very essential.

Flood geomorphology is concerned with the processes, forms, effects, and causes of floods (Baker et al., 1988). In certain hydro-geomorphic environments, such as the seasonal tropics floods play a dominant role in shaping the river channel and the landscape (Wohl, 1992b; Gupta, 1995a). The size of a channel and the amount of sediment load carried by the river are dependent to a large extent on the magnitude, frequency and hydraulic properties of the high flows. Infrequent large floods that occur at an interval of several decades are associated with much higher levels of power expenditure and thus are capable of producing major channel changes and movement of coarse sediments (Baker and Kale, 1998). A large discharge event on the river geomorphologically effective can be determined by understanding the channel geometry and the hydraulic characteristics of floods. In this chapter, therefore, an attempt has been made to describe and analyze the channel size and shape of the Savitri River to understand
the relative importance of low and high flows. In addition to this, return periods are calculated by using Gumbel’s extreme value distribution and flood inundation area has also identified and marked with the help of inundation mapping.

5.2 Channel morphology:

River channel morphology includes basically four parameters namely channel shape, channel size, channel slope and channel pattern (Gupta, 1995). The channel geometry plays a role of considerable importance in determining the geomorphic effect of floods (Kochel, 1988). In terms of processes, it is necessary to distinguish between alluvial and bedrock channels. These two types of channel systems have distinctly different flow processes (Baker and Kochel, 1988) and this has a considerable bearing on the nature and amount of sediment transport, and the type of geomorphic work performed during large floods as well as the response of channels to floods (Baker and Kale, 1998). Therefore, a brief description of the two main types of Savitri channel systems is given in the following paragraphs.

5.2.1 Types of channel systems – alluvial and bedrock

The Savitri River flows through both bedrock and alluvial reaches. In the upstream area, the channel of the Savitri River is predominantly developed in bedrock basalt. The alluvial Savitri is downstream. Although the river regime characteristics and fluvial processes remain same, there are striking differences in the channel morphology and bed material (fig.no.5.1).

(1) Bedrock channel

In the source region up to Birwadi, the Savitri River flows primarily through bedrock. In this section, the channel is bounded by low rocky banks or occasionally by alluvium. The channel bed is either covered by coarse bedload material or is characterized by bare rock exposures mean sheet rock and gravel bars. In some reaches, such as near Kal confluence, at Birwadi and Loharmal, basalt is exposed on the bed. Evidence of flood erosion is seen in the form of potholes, scour lines, flute marks and polished rock surfaces in this reach. Rapids are also seen in this section.
(2) Alluvial channel reaches

The alluvial Savitri is downstream of Mahad up to the mouth. In the alluvial reach the river is deeply incised into alluvial deposits and the river displays a channel-in-channel physiography. Usually high alluvial banks enclose a large channel inside, islands and patches of flood plain. In general, the incised alluvial channel is box-shaped in cross section with pool-riffle bed topography. The gradient of the river is very low, and in plain the river displays a meandering channel pattern. In the alluvial sections, the channel bed is generally sandy with high proportion of pebbles and cobbles. These coarse sediments control the channel bed morphology. In the middle reaches, the high banks and islands of the Savitri River are extensively fragmented by islands, giving rise to bifurcated channel topography.

5.2.2 Change in the width-depth ratio with discharge

The channel of the Savitri River is box-shaped, with more or less flat channel floor and high banks. Therefore, during the dry season and during low flows the water spreads, and the width is high and depth is low. Consequently, the width-depth ratio is high and the channel reflects all the characteristics of a shallow, wide channel. However, in response to heavy rainfall as the stage and discharge increases, there is an increase only in the depth of flow. As a result, the width-depth ratio decreases, and the hydraulic efficiency increases dramatically. There is a noteworthy drop in the ratios in the middle reaches, because of the very wide nature of the rectangular-shaped channel of the Savitri in these sections.

Comparative analysis was carried out to evaluate the relationship between width-depth ratio and discharge for two sites in the bedrock reaches of the Savitri River, namely Bhave and Birwadi. This analysis indicates that the rate of change in width-depth ratio with discharge is highest for the Birwadi site where the channel is almost rectangular in shape. In comparison, at Bhave, the rate of change is lowest because of deeper channel. On the basis of the channel shape, an important conclusion that emerges is, the flows become deeper and efficient as the discharge increases. This therefore, suggests that large flood flows are geomorphologically more effective than low or moderate flows. Other rivers of
the seasonal tropics have also been found to behave in the same manner (Gupta, 1995a; Deodhar and Kale, 1999).
FIG.NO.5.1: GEOMORPHIC SKETCHES OF VARIOUS CHANNEL REACHES OF SAVITRI RIVER FROM SOURCE TO MOUTH
5.3 Channel gradient:

The channel gradient is one of the important morphological parameters dictating the unit steam power and geomorphic impact. Slope values determined are in the range of 20° to 0°. Most of the slope angle values are in the range of 17° to 2°. The scarp region and sides of plateau in the coastal belts are of higher slopes. The slopes of ridges are in the range 15° to 10°. Undulating terrain has slope angle in the range of 7° to 2°. Some of the regions are levelled ground which has slope angle from 2° to 0°. It is noted that the Mangaon depression has low slope angles in the range of 5° to 2°. Elevation versus distance for the Savitri River and its tributaries has been measured from topographic maps is of 1:2, 50, 000 scales. From this data, longitudinal profile for the Savitri river and its tributaries are drawn (Fig.5.2). Profiles are steep in the source region and become horizontal near the mouth. These profiles are useful to state whether streams are in the state of graded or upgraded river due to rejuvenation. The rate of decrease in the channel gradient is higher in the upper reaches and lower in the middle and lower reaches of the river. The nature of downstream changes in the gradient suggests that decreasing slope may offset any increase in depth and velocity as flood moves downstream.
FIG. NO. 5.2: CONTOUR MAP OF SAVITRI BASIN

FIG. NO. 5.3: LONGITUDINAL PROFILE OF SAVITRI & KAL RIVER
### TABLE NO. 5.1: NAGESHWARI RIVER

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<th>Height in Mts</th>
<th>ΔH in Mts.</th>
<th>Length in Km AL</th>
<th>Cumulative Len. in Km.</th>
<th>L Δ -- 2</th>
<th>L</th>
<th>SL</th>
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### TABLE NO. 5.2: KAL RIVER

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### TABLE NO. 5.4: KAL NADI

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#### 5.4 Stream Length Gradient Index (SL):

The stream length gradient index (SL) has been developed by Hack (1973). He defined SL index for a particular segment of stream by following equation,

\[
SL = \frac{\Delta H}{\Delta L} \times L
\]

Where, \(\Delta H\) is change in elevation of the steam segment, \(\Delta L\) is the length of steam segment and \(L\) is the total length from the drainage divide to the centre of stream.
segment. According to Hack, index is very sensitive to change in slope and useful
to evaluate possible to tectonic activity, rock resistance and topography. Anomally high values of SL index indicate possible location of uplift. Killer (1977) used this method to the San Garbrial Mountain southern California, which has been uplifted to several thousand meters elevation. The SL values are shown in table no. 5.1 to 5.4. Fig.no.5.3 & 5.4 represents the curves for longitudinal profiles of Savitri River and its tributaries. Longitudinal profile for Savitri River and its tributaries shows steep initial segment of curve whereas very gentle slope for the downstream segment. The profile of Kal nadi and Nageshwari River show distinct knick point. In the zone of knick point the SL values are higher than its upstream and downstream segments. Thus, these zones possibly represent the fault zones.

5.5 Channel geometry Parameters:

The dimensions of a river channel in cross section is defined as channel morphology (Petts and Foster, 1985). The river channel morphology is an expression of balance between stream power and the resistance of material comprising the channel perimeter (Morisawa, 1985). The appearance of a river is divided into mainly three categories namely channel size and shape, channel slope and channel pattern.

In the following section, the morphological characteristics of the Savitri River have been described with reference to the channel reach and cross section variables (Table no. 5.5). The data regarding the cross sectional parameters was obtained from field surveys, from Central Water Commission (CWC) and from Mahad Irrigation Department. Table no. 5.6 gives the list of sites. Information regarding channel slope (S), channel length (L), and catchment area (A) for the sites was obtained from toposheets, CWC and field surveys. The channel reach and cross section variable data for four sites is given in table no. 5.7.
### TABLE NO. 5.5: CHANNEL CROSS SECTION AND REACH VARIABLES USED IN THE PRESENT STUDY

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<td>M</td>
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<td>M</td>
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<td>Maximum depth</td>
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<td>M</td>
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<td>Flow velocity</td>
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<tr>
<td>Catchment area</td>
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<tr>
<td>Channel length</td>
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### TABLE NO. 5.6: LIST OF CHANNEL CROSS SECTION SITES OF THE SAVITRI RIVER

<table>
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<td>6</td>
<td>Mahad</td>
<td>W,D,L</td>
</tr>
<tr>
<td>7</td>
<td>Gothe khurd</td>
<td>D,L</td>
</tr>
<tr>
<td>8</td>
<td>Varathi</td>
<td>D,L</td>
</tr>
<tr>
<td>9</td>
<td>Ambet</td>
<td>D,L</td>
</tr>
<tr>
<td>11</td>
<td>Adhi</td>
<td>D,L</td>
</tr>
<tr>
<td>11</td>
<td>Bankot creek</td>
<td>L</td>
</tr>
</tbody>
</table>
TABLE NO. 5.7: CHANNEL MORPHOLOGIC VARIABLES OF SOME CROSS SECTIONS OF THE SAVITRI RIVER

<table>
<thead>
<tr>
<th>No.</th>
<th>Site</th>
<th>A</th>
<th>L</th>
<th>W</th>
<th>D</th>
<th>Ca</th>
<th>F</th>
<th>Wp</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bhave</td>
<td>813</td>
<td>40.5</td>
<td>150</td>
<td>3.6</td>
<td>420</td>
<td>41.66</td>
<td>165</td>
<td>2.54</td>
</tr>
<tr>
<td>2</td>
<td>Birwadi</td>
<td>909</td>
<td>44.5</td>
<td>200</td>
<td>5.20</td>
<td>1380</td>
<td>38</td>
<td>240</td>
<td>5.75</td>
</tr>
<tr>
<td>3</td>
<td>Mahad</td>
<td>1032</td>
<td>52.5</td>
<td>270</td>
<td>5</td>
<td>1230</td>
<td>54</td>
<td>540</td>
<td>1.73</td>
</tr>
<tr>
<td>4</td>
<td>Dasgaon</td>
<td>1501</td>
<td>58.5</td>
<td>375</td>
<td>5.75</td>
<td>1622</td>
<td>52</td>
<td>1251.31</td>
<td>2.409</td>
</tr>
</tbody>
</table>

Min   150  3.6  420  38  165  1.73
Max   375  5.75 1622 54  1251.31 5.75
Mean  248.75  4.89 1163 46.41 549.08 3.11
Σ     97.5  0.92 520.99 7.79 495.40 1.80
Cv %  39.14 18.72 44.80 16.79 90.22 57.84

(Sources: Mahad Irrigation Department; Field surveys and other; A= Catchment area in Km²; L = Distance from source in km; σ = Standard deviation, Cv = Coefficient of variation in %.)

5.6 Channel Forms and Processes:

Channel forms are the outcome of river processes and are highly irregular in outline and variable in nature (Morisawa, 1995). In order to define channel morphology in terms of shape, size and efficiency, a number of variables have been used in fluvial geomorphology. These include channel width, depth, channel cross-sectional area, wetted perimeter, hydraulic radius and width-depth or form ratio (Petts and Foster, 1985). These variables are usually obtained with reference to the bankfull channel dimensions. In the present study, the different cross section parameters have been obtained with reference to the maximum annual peak discharge (Qmax) observed at each cross section.

5.6.1 Channel Form

Generally, the channel size and shape of the channel is the ratio of width and depth and it is a function of the discharge and its variations, the texture and quantity of sediments passing through the section and the nature of the bed and bank material (Leopold et.al., 1964).
(1) Channel Width (W):

Fig.no. 5.5 gives the cross sections along the Savitri River. These cross sections show that the channels are narrow in upper reaches and significantly wider in the middle and lower reaches, indicating that the width increases downstream more rapidly than depth. The average channel width of the Savitri River is about 248.75 m and it varies from approximately 150 m at Bhave in the upper reach part to 375 m at Dasgaon in the alluvial section (table no.5.7). By and large, in spite of the local variations in the channel width, there is a gradual increase in the width with an increase in the distance from the source.

![Graphs showing cross sections of Bhave and Dasgaon](image_url)

**FIG.NO. 5.5: CROSS SECTIONS AT VARIOUS SITES ALONG SAVITRI RIVER**

(2) Channel depth (D)

Channel depth is an important parameter that determines the power per unit area and boundary shear stress at a cross section. The maximum channel depth of the Savitri River is less upstream of Cholai Nadi and Savitri River confluence. It ranges between 2 m at Sakhar and 30 m at cholai nadi and Savitri
confluence. The average channel depth of whole Savitri channel from source to mouth is 9.18 m. There is gradual increase in depth in the downstream direction. But unlike width, the rate of increase in the depth is lower. From middle reach part depth suddenly decreases from Birwadi up to the mouth.

(3) **Hydraulic radius (R)**

Hydraulic radius, a measure of channel efficiency (Petts and Foster, 1985), ranges from 1 to 6 m. The average hydraulic radius is about 3.11 m. Such high hydraulic radius value reflects the moderate efficiency of the channel of the Savitri River. Like the channel depth, the hydraulic radius also goes on increasing with an increase in distance from the source and in catchment area.

(4) **Channel capacity (Ca)**

The channel capacity is a fundamental scale variable and is usually defined as the cross sectional area. It, therefore represents the amount of water and sediments, which a channel can accommodate (Petts and Foster, 1985). The channel capacity of the Savitri River ranges between 420 and 1622 m$^2$. The average channel capacity is 1163 m$^2$. The existing channel sizes at different reaches of the Savitri River indicate that the flows of sufficient magnitude have occurred in the past to create such a large channel.

(5) **Form ratio (F)**

The form ratio is the ratio of channel width and depth. It is a measure of channel shape and is related to the sediment transport and boundary resistance (Schumm, 1960). In case of the Savitri River the form ratio varies from 38 to 54. The width-depth ratio was found to be highest at Birwadi due to wide channel and lowest at Bhave due to upper reach part. The average width-depth ratio is about 46.41. For most of the sites, the form ratio values are below 46.41. This indicates that the channel of the Savitri River is predominantly deep and narrow.
5.6.2 Channel Pattern:

Channel pattern is usually associated with alluvial channels. The channel pattern or map view of a river is usually considered as straight, meandering and braided (M. Morisawa, 1985). The Savitri river channel is meandering and also braided at middle reach part. It is meandering at Birwadi and braided channel is developed at Dasgaon.

(1) Meandering channel:

A stream channel having sinuosity index more than 1.5 is defined as meandering and is the most common channel pattern to be found anywhere along the longitudinal course of a river mainly alluvial rivers. The meandering channel is characterized by pools at the bends and riffles at the crossovers of the river course. Such pools and ripples features are seen in Savitri river channel. According to J.C.Brice (1964) sinuosity index is calculated by following formula for Savitri reach from Mathachiwadi to Birwadi Kal Confluence with Savitri:

\[
SI = \frac{\text{Length of channel}}{\text{Length of meander belt axis}}
\]

\[
30100
\]

\[
SI = \frac{30100}{23400} = 1.28
\]

Here, sinuosity index value is 1.28 means it is close to 1.3. It means this channel reach is moderately meandering and braided in pattern. Besides this, in this W/D ratio is 48, means it is more than 40, so here channel aggradation is more and mid-channel bars are also formed. Therefore in this section islands are developed on large scale.

(2) Braided Channel:

A braided channel pattern is characterised by multiple channels wherein these channelways are divided by bars and islands and are always shifting within highly erodible river banks. Such type of braided channel is observed in Savitri River channel at Gothe Khurd site.
5.7 Types of flood:

River Flood:

River floods are a natural and inevitable part of life in riverside area. Low laying areas near rivers, streams, lakes, and reservoirs are susceptible to river floods. Some river floods occur seasonally when winter or spring rains fill river basins with too much water too quickly. Other can occur from slow-moving low pressure system.

Flash flood:

Flash flood can occur within a few minutes or hours of heavy rainfall or from a dam or levee failure. These floods can destroy structures, down trees, roll boulders, and create new waterway. Rapidly rising water can reach heights of 30 feet or more furthermore; flash flood producing rains can also trigger catastrophic mudslides. You may not always have a warning of these sudden and deadly floods.

Area Flood:

Standing water in a low- laying area such as an open field is an example of an area flood. Significant agricultural losses and displaced livestock can occur with these floods. In addition, stagnant water from this type of flooding can serve as a breeding ground for insects and diseases.

5.8 Causes of flood:

Heavy down pore in the form of rain brings down more that can be disposed of by combined factors natural and manmade systems, causes flooding. The river overflow embankments may be breached. In recent times, the impact of meteorological and physical factors has been accentuated by unwanted human activities.

Physical Factors:

- Large Catchment Area.
- Inadequate Drainage Arrangement.

Human Factors:

- Deforestation.
- Siltation.
Faulty Agricultural practices.
Faulty Irrigation Practices.
Bursting of Dams.
Accelerated Urbanization.

Meteorological Factors:

- Heavy Rainfall.
- Tropical Cyclones.
- Cloud Burst.

In the Savitri basin various factors are responsible for flooding such as erosion and silting, reduced channel capacity, increased meandering, landslides, heavy rainfall, bottleneck shape of river channel near mouth retardation of flow due to tidal effect etc.

5.9 Effects of flooding:

Floods have multipronged effects on human life. A more frightening fact is that floods are becoming more damaging as their frequency, intensity and magnitude increases with the passage of time. Flooding inflicts both Direct and Indirect losses that can be classified as primary and secondary.

**Direct Effects:**

- Loss of life.
- Disease caused by contamination of water supply.
- Famine caused by damage to crops.
- Stress: physical and mental health problems.
- Damage to infrastructure: Roads and Communications.
- Loss in the value of properties and insurance premiums.
- Disturbance in Biodiversity.

**Indirect Effects:**

- Disruption to traffic which costs business money, and transport.
- Effects of reduced spending power in the local area as people lose money, jobs etc.
- Loss in tourist spending in the area.
- People leaving the area.
- Less investment in area.
GIS and Remote Sensing are incredibly useful and effective tools in disaster management. These technologies have been the object of substantial interest for all countries and bodies concerned with space and in exacting emergency services and disaster management. In disaster management, the objectives of disaster experts are to monitor the situation, simulate the complicated disaster occurrence as accurately as possible so as to come up with better prediction models, suggest appropriate contingency plans and prepare spatial databases. Remotely sensed data can be used very effectively for quickly assessing severity and impact of damage due to earthquake, landslides, flooding, forests fires, cyclones and other disasters. In the present chapter this GIS technique is used for inundation mapping of flood affected areas in Savitri basin.

5.10 Flood Inundation Mapping:

Accurate information on flood inundation, flood zonation is essential for designing a sound planning and management. It also provides the base line data required for proper understanding for how the floods have occurred in the past/ and what magnitude of flood is excepted to occur in the future. This study will also yield valuable information for analysis of flood disaster. It is of great use to the recourse managers, planners, and administrators as it provides the information that will be helpful in resolving the conflict between humans and functioning of natural system.

In this chapter flood inundation mapping for 2005 and 2007 flood events has been analysed. For this all HFL markings of 2005 and 2007 events were recorded. Separate flood inundation maps were created for above mentioned flood events. The total area, total villages submerged and spatial extent of respective flood events computed.
5.10.1 2005 flood events-

Analysis with the help of Arc-GIS reveals that the area and the extent of flooding was greater than previously recorded flood events. Inundated area of Savitri River is presented in figure which shows the villages that were affected due to the flood which occurred in 2005 on the basis of HFL collected on the ground survey. 2005s HFL in and around the Mahad city is 18.5 mts above from MSL. Due to this event about 10% of the area of Savitri River basin was occupied by flood water which is 210.62 sq.km and whole Mahad city and its surrounding 86 villages were affected by flood.
The two photographs, photo no. 1 and 2 which show the HFL readings on the houses are taken on the field. Photo no.1 is taken in Vahur village near to Mahad city. Photo no.2 is taken from the Mahad Macchi Market which is along with the river channel and represents the various flood events marking. These two photographs are the best proof for the 2005 flood event.

5.10.2 2007 Flood Event:

Analysis of the 2007 flood event has also been done with the help of Arc GIS in which inundated area is captured on the basis of flood level marking present near Mahad Macchi market. See photo 2. 2007 flood water level in and around Mahad city is 17.5 mts. 2007 flood event occupied 134.66 sq.km with Mahad city and its surrounding 32 villages. Inundated area of 2007 flood event is approximately 6% of the total basin area.
FIG.NO.5.8: INUNDATED AREA OF 2007 FLOOD OF SAVITRI RIVER BASIN.

In fig. no. 5.9 comparison between 2005 and 2007 flood event has been done on the basis of HFL in Arc GIS. The light blue colour represents 2005 flood inundated area and dark blue colour represents 2007 flood inundated area. The above map clearly indicates that the flood of 2005 has occupied comparatively more area than that of 2007.
FIG.NO. 5.9: COMPARISON BETWEEN 2005 AND 2007 FLOOD INUNDATION AREA.

FIG.NO.5.10: OVERLAY MAP OF 2005 AND 2007 FLOOD INUNDATED AREA.
5.10.3 Flood peak estimation of various frequencies:

Irrigation dept, Govt. of Maharashtra report on Mahad city have analysed different storm event by adopting the hydro meteorological approach. Recurrence interval for different storm depths for 24 hours storm duration has been computed, they are as follows:

**TABLE NO. 5.8: 24 HRS STORM DEPTHS, FREQUENCY WITH FLOOD PEAK**

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Frequency Year</th>
<th>24 hr. storm depth.</th>
<th>Flood Peak cu.m/sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 in 20</td>
<td>440 mm</td>
<td>7267</td>
</tr>
<tr>
<td>2</td>
<td>1 in 50</td>
<td>480 mm</td>
<td>7939</td>
</tr>
<tr>
<td>3</td>
<td>1 in 100</td>
<td>520 mm</td>
<td>8612</td>
</tr>
<tr>
<td>4</td>
<td>1 in 200</td>
<td>520 mm</td>
<td>9500</td>
</tr>
<tr>
<td>5</td>
<td>SPF (will have 1 in 700 year)</td>
<td>565.7 mm</td>
<td>12122</td>
</tr>
</tbody>
</table>

Source: Irrigation Department Report, Govt. of Maharashtra.

5.11 Flood Frequency Analysis:

Flood frequency is the statistical method of frequency analysis for computing the magnitude frequency relationship of the event. The values of the annual maximum flood from the given catchment for the large number of years are arranged in the decreasing order of magnitude and the probability P of each event being equaled or exceeded is calculated by the formula:

\[ P = \frac{m}{N+1} \quad (1) \]

Where, \( m \) is the order of the event, \( N \) is total number of events in the data. The recurrence interval \( T \) is calculated as,

\[ T = \frac{1}{P} \quad (2) \]

Chow (1951) demonstrates that most frequency distribution functions applicable in the hydrological studies can be expressed as the general equation of hydrologic frequency analysis:

\[ x_T = x_m + k\sigma \quad (3) \]
Where, \( k \) is the frequency factor, \( x_T \) is the flood magnitude of given return period \( T \), \( x_m \) is the mean of the recorded floods and \( \sigma \) is the standard deviation of the variate. There are many techniques for the estimation of discharge using frequency factor. For the present study, Gumbel’s extreme value distribution, and log-Pearson type III distribution technique is used.

### 5.11.1 Gumbel’s Extreme Value Distribution

Gumbel’s extreme value distribution is based on the theory that the extreme event is unlimited and therefore the most suitable distribution to the extreme value data is “double exponential type” (Pal, 1998). According to his theory the probability of occurrence of an event equal to or larger than the value of \( x_0 \) is

\[
P(X \geq x_0) = 1 - e^{-e^y} \quad (4)
\]

Where, \( e \) is the base of natural logarithm and \( y \) is the dimensionless number given by

\[
y = \frac{1}{0.78} \times \left( \frac{x_T - x_m}{\sigma} \right) + 0.577 \quad (5)
\]

Where, \( x_T \) is the event of discharge in \( T \) year return period, \( x_m \) is the arithmetic mean, \( \sigma \) is the standard deviation of all the data in the series.

The 18-year peak discharge of Savitri basin in Bhave and Birwadi is arranged in the descending order. The plotting position recurrence interval \( T_p \) for each discharge is obtained by equation (1).

Mean peak discharge \( x_m \) at Bhave is 164.84 cumecs and at Birwadi is 1398.5 cumecs and the standard deviation \( \sigma \) for the series is 89.83 cumecs at Bhave and at Birwadi it is 421.98 cumecs. In the equation (3) \( k \) or the frequency factor is calculated with the formula

\[
k = y_T - y_n / \sigma \quad \text{.....(3)}
\]

Where \( y_T \) is the reduced variate given by the function \([\ln T/T-1]\). \( \sigma \) is the reduced standard deviation, and \( y_n \) is the reduced mean derived from the table of reduced mean and standard deviation. With all the values derived, the value of \( x_T \) is
calculated for River Savitri for 10, 20, 50, and 100 years. The values from the above calculation are given in the table 5.9. The return periods values calculated for Mahad city, by PWD Mahad have also been shown in table no. 5.10

**TABLE 5.9 RETURN PERIODS AT BIRWADI STATION FOR GUMBEL DISTRIBUTION**

<table>
<thead>
<tr>
<th>Return Periods T (years)</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_T$</td>
<td>-0.05473</td>
<td>-0.02664</td>
<td>-0.01049</td>
<td>-0.00522</td>
</tr>
<tr>
<td>K</td>
<td>-0.57621</td>
<td>-0.5193</td>
<td>-0.48305</td>
<td>-0.46937</td>
</tr>
<tr>
<td>$x_T$</td>
<td>1155.352</td>
<td>1179.365</td>
<td>1194.662</td>
<td>1200.435</td>
</tr>
</tbody>
</table>

**TABLE 5.10 RETURN PERIODS AT MAHAD STATION ACCORDING TO PWD, MAHAD**

<table>
<thead>
<tr>
<th>Return Periods T (years)</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>700</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_T$</td>
<td>7267</td>
<td>7939</td>
<td>8612</td>
<td>9500</td>
<td>12122</td>
</tr>
</tbody>
</table>

Source: (Mahad PWD Department, Mahad)

Assuming that the flood peaks of 1 in 25, 1 in 50, and 1 in 100 years fit in Gumbel’s distribution, the flood peak of 1 in 200 years reads 9500 cumecs where it considered as 200 years frequency flood while flood peak of 1 in 700 years reads 12122 cumecs.

As per Technical report of Irrigation dept, Govt. of Maharashtra, Dasgaon bridge afflux for 5.7 m flood level with cross section area of 4686.25 sq.m and velocity of flood flow of 1.007 m/sec comes around 4719 cu. m/sec.

By comparing the flood peak values of 20, 50, 100 and 200 year frequency, is is clearly understood that 2005 flood event was not the exception or above normal flood. As the total discharge for the event is approximately half to any flood peak value. It is also revealed that such a event can occur twice in 20 years.
5.12 Calculation for flood discharge at 8.00 m flood level in 1989 years flood:

Cross section area \( A \) = 14\times 30 = 420 sq.m.
Perimeter \( P \) = 165m

\[ R^{2/3} = 1.86 \]
\[ V = \frac{(1/n) \times R^{2/3} \times s^{1/2}}{1/1850} \]
\[ = 33.34 \times 1.86 \times 0.023 \]
\[ = 1.44 \text{ m/sec} \]
\[ Q = A \times V \]
\[ = 420 \times 1.44 \]
\[ = 604.80 \text{ cumecs or 605 cumecs} \]

Cross section area \( A \) = 46\times 30 = 1380 sq.m.
Perimeter \( P \) = 240m

\[ R^{2/3} = 3.21 \]
\[ V = \frac{(1/n) \times R^{2/3} \times s^{1/2}}{1/1850} \]
\[ = 33.34 \times 3.21 \times 0.023 \]
\[ = 2.46 \text{ m/sec} \]
\[ Q = A \times V \]
\[ = 1380 \times 2.46 \]
\[ = 3394.80 \text{ cumecs or 3395 cumecs} \]

Cross section area \( A \) = 41\times 30 = 1230 sq.m.
Perimeter \( P \) = 540 m

\[ R^{2/3} = 1.73 \]
\[ V = \frac{(1/n) \times R^{2/3} \times s^{1/2}}{1/1850} \]
\[ = 33.34 \times 1.73 \times 0.023 \]
\[ = 1.33 \text{ m/sec} \]
\[ Q = A \times V \]
\[ = 1230 \times 1.33 \]
\[ = 1635.90 \text{ cumecs or 1636 cumecs} \]

Total discharge at R.L. 8.00 m. = 605 + 3395 + 1636 = 5636 cumecs

5.13 Calculation for flood discharge at 8.40 m flood level in 1994 years flood:

Cross section area \( A \) = 17\times 30 = 510 sq.m.
Perimeter \( P \) = 180 m

\[ R^{2/3} = 2.00 \]
\[ V = \frac{(1/n) \times R^{2/3} \times s^{1/2}}{1/1850} \]
\[ = 33.34 \times 2.00 \times 0.023 \]
\[ = 1.53 \text{ m/sec} \]
\[ Q = A \times V \]
\[ = 510 \times 1.53 \]
\[ = 780.30 \text{ cumecs or 780 cumecs} \]

Cross section area \( (A) = 50 \times 30 = 1500 \text{ sq.m.} \)

Perimeter \( (P) = 240 \text{ m} \)
\[ (R) = A/P = 1500/240 = 6.25 \]
\[ R^{2/3} = 3.39 \]
\[ V = (1/n) \times R^{2/3} \times s^{1/2} \]
\[ = 33.34 \times 3.39 \times 0.023 \]
\[ = 2.60 \text{ m/sec} \]
\[ Q = A \times V \]
\[ = 1500 \times 2.60 = 3900 \text{ cumecs} \]

Cross section area \( (A) = 49 \times 30 = 1470 \text{ sq.m.} \)

Perimeter \( (P) = 550 \text{ m} \)
\[ (R) = A/P = 1470/550 = 2.67 \]
\[ R^{2/3} = 1.93 \]
\[ V = (1/n) \times R^{2/3} \times s^{1/2} \]
\[ = 33.34 \times 1.93 \times 0.02 = 1.48 \text{ m/sec} \]
\[ Q = A \times V \]
\[ = 1470 \times 1.48 \]
\[ = 2176 \text{ cumecs} \]

**Total discharge at R.L. 8.40 m. = 780 + 3900 + 2176 = 6856 \text{ cumecs}**

5.14 **Calculations of afflux for Konkan Railway Bridge across River Savitri near Dasgaon village:**

Afflux calculated as per Molsworth Formula

Molsworth Formula = \[ h = \left[ \left( v^{2/17.88} \right) + 0.01524 \times (A/a)^{2-1} \right] \]

Where, \( h = \) Afflux in meters
\( V = \) velocity in unobstructed flow in m/sec
\( A = \) unobstructed area of cross section of flow
\( a = \) obstructed area of cross section of flow.

Area of unobstructed flow as per cross section = 4686.25 sq.m.

Obstructed area of flow = 2320.69 sq.m.

Hence, \[ h = \left[ ((1.007)^{2/17.88} + 0.01524) \times (4686.25/2320.69)^{2-1} \right] \]
\[ h = >0.22 \text{ mts.} \]

As per above calculations water afflux at Railway Bridge is more than 0.22 metres which is responsible for flood water stagnancy in the villages which are near this bridge.
5.15 Past events of floods in Savitri basin:

Since heavy rains and associated floods are an inherent characteristic of the Savitri river basin it is not surprising that there are several references to such extreme events in the historical reports of Mahad Nagarparishad, Gazeteers of Kulaba (Raigad) and Mahad. The most useful information is available for the middle reaches of the basin, because some historical villages and towns are located on or near the banks in this part of the basin. Of the several towns and villages, Birwadi, Mahad, Dasgaon are some important historical towns for which some information is available.

The documentary information about the historical floods was primarily obtained from District Gazetteer and other unpublished reports. Apart from these major sources of information, additional data regarding recent and past floods were collected from individuals during visits to the villages and towns located on / near the banks of the Savitri River. During such field visits it was found that several villages in the middle reach of the Savitri basin, which are presently located away from the banks and they constructed new multi-storeyed buildings they leave in first floor and total ground floor has been used for parking purposes, were severely affected by some of the historic floods. Therefore, information regarding these villages was also collected through interviews with the local people in some villages.

Furthermore, attempts were made to locate man-made High Flood Level (HFL) marks on modern and historical structures, such as bridges, temples, buildings etc. Such HFL marks were found on three bridges located in the middle reaches of the Savitri River at Gothe Bridge, Tol Phata Bridge and Dasgaon Konkan Railway Bridge.

Five major floods are discussed briefly in the following paragraphs.

The 1923 severe past flood

The flood that occurred in 1923 has been described in considerable details in the district Gazetteer and some historical reports dealing with the study area. This flood has occurred on 24th July 1923 on 12.00 pm at mid night. Therefore, 700 to 800 people and many cattle die in Mahad city due to this flood. Other so many villages like Dasgaon, Dadli, Shirgaon, Gothe and Ravdhal are also
submerged in this flood. According to interviews and Mahad nagar parishad reports this flood level was very high than other past and recent flood levels. This flood level was about 2 m higher than the previously and recent known flood level. Nearabout 30 -40 villages were completely destroyed by the flood.

**The 1954 severe flood in the middle Savitri Basin**

As per verbal information provided by villagers, the 1954 flood appear to be the largest flood of the recent times. But the flood level was less than 1923s flood and damage was also less than that flood. Almost all the villages located on the banks in the middle reaches were severely affected by the flood. This flood was also caused by heavy rainfall and tidal effect.

**The 1976 flood in the middle Savitri Basin**

The information about this flood is mentioned in reports of PWD Mahad. So many villages which are near the Savitri Bank are submerged due to this flood.

**The 1989 flood in the middle Savitri Basin**

This flood was occurred on 23rd and 24th July 1989. The evidences of this flood are available in district Gazetteer and some historical reports dealing with the study area. The HFL mark is also seen on the pillar of Buiding in Mahad Macchi Market. The flood level was 8.00 m and the duration of this flood was 15 hrs. This flood was also result of tidal effect and heavy rainfall.

**The 1994 flood in middle Savitri Basin**

This flood was occurred in 27th and 28th June 1994. The HFL marks are also available at four sites these are House wall at Ravdhal, Gothe Bridge, Tol Phata Bridge, House wall at Vahur and pillar of Buiding in Mahad Macchi Market. The flood level of this flood was 8.40m. Part of Mumbai-Goa National Highway (NH-17) and many villages are submerged due to this flood. This flood level was more than 1989s flood. Heavy rainfall is responsible for this flood.

### 5.16 Conclusion:

According to the 2005 and 2007 data, which is generated on the basis of water/flood level present near Mahad macchi market, the High Flood Level (HFL) in Mahad is 18.5 mts and 17.5 mts respectively, whereas according to Irrigation
Department Flood report 1989 and 1994 the HFL is 8.00 mts and 8.40 mts respectively in Mahad.

Comparing above HFL, it can be stated that 2005 flood event has occupied greater area across the river channel as well as Mahad city. In 2005, flood water occupied 210.62 sq. km area which is almost 10% to the total basin area of the Savitri River. In the Savitri Basin, the years 1923, 1954, 1976, 1989, 1994, 2005 and 2007 experiencing major and devastating floods. The entire floods 1923s and 2005s both floods were very high and destructive.

The following factors are responsible for the flood Inundation in and over the area of Mahad City:

Konkan Railway constructed a railway bridge near Dasgaon across river channel. For that purpose they constructed embankment. Presence of embankment across the river channel has caused impounding of river water upstream to bridge. Because this water is retained and spread over the river bank. It is suggested that islands present in upstream and downstream of Savitri and Gandhari River should be removed so that these two tributaries will have significant river channel that will accommodate the flood water. Tidal effect, physiographic structure and urbanization has influenced in increasing the water level in the river channel. A sand excavation is the best example.