CS/AR-28/97-98

# FLOOD STUDIES IN SATLUJ BASIN


NATIONAL INSTITUTE OF HYDROLOGY
JALVIGYAN BHAWAN
ROORKEE - 247 667 (UTTARANCHAL)



1997-98

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## ABSTRACT

Flood in monsoon months is a major problem in northern rivers in India in spite of various flood control measures adopted against the floods. Large floods inundate vast expanse of land adjoining the river course. Flood inundation/ flood plain features mapping and river planform measurements are done for Satluj. The river lies in the Indus system. A part of the river reach (181 km) in Punjab downstream from Roopnagar is selected for planform study. An upstream reach of 50 km in the study area is selected for inundation study. Flood inundation mapping is done for flood of September 1988 using digital image processing technique. IRS LISS II digital data and FCC at the scale of 1:250000 are used. Softwares used are ILWIS 2.2 and PC- ERDAS 7.5. The ILWIS is used in data encoding, image rectification and output. ERDAS is used for image processing and GIS manipulation. Mainly areas on the right flank of the river are inundated. On the left flanks storage of rainwater on depressions occurs. A flood damage analysis is done by assigning a qualitative damage scale of numbers 1 to 10 in increasing order of damage. The land use and cover (next season) and flood inundation maps are assigned weights for the analysis. The results will be useful for further investigation in field and for planning flood control measures.

Percentage areas with low and high flood damage are respectively 2.2 and 11.9. The areas are respectively 20 and 110 sq. km. The Large high flood damage class is due to the presence of 90% agricultural land. The 'high damage' area is over estimated since the crop map for the flood season is not used. The causes of the flood are over topping of the banks, floods in the hill torrents and occurrence of low lying areas with poor drainage. Flooding has occurred predominantly on right flank of the river up to the Bist Doab and Nawhashar canals. Hill torrents cause sand casting. Hydrometeorology of the flood of Sept. 1988 and conveyance capacity of the canalised Satluj downstream of Roopnagar headworks are also described.

# 1 INTRODUCTION

International flood commission on Irrigation and Drainage has defined flood as markedly high discharge or stage in the river and inundation of adjoining low lying areas. Flood is caused by many reasons namely runoff caused by cyclonic storms coupled with high antecedent moisture conditions in the catchment, cloud burst, dam break, synchronisation of high flows in tributaries, drainage congestion etc. From year to year and within a year also the flood discharges in a river varies. This makes its study difficult.

## 1.1 REMOTE SENSING AND GIS APPLICATION TO FLOOD STUDIES

Remote sensing is a technique in which the electromagnetic radiation sensors are used to obtain information about the earth's surface. The objects on the earth's surface possess typical spectral signature. This makes their identification from remotely sensed data easy. For example in a flood inundation mapping from remotely sensed data, the inundated areas can be identified very easily due to low spectral reflectances of water in visible and near infrared bands.

The remotely sensed data are poor representation of the earth surface. This requires application of digital processing or visual interpretation of satellite data. The data are available in both digital and visual forms. The digital data are available as digital numbers usually 0 to 255. But this also depends on the quantization level of the data. These numbers represent the spectral response at the pixel locations in the ground. These are used in digital processing of the data. The digital processing techniques are described below:

Digital classification: Digital classification is applied to the multispectal digital data to extract information from them. The classification uses the spectral properties of objects. There are mainly two approaches used in this namely supervised and unsupervised. In the unsupervised techniques, the inherent grouping in the multispectral data is utilised to form groups. This is performed automatically by the computer. The groups or clusters so formed are assigned thematic classes.

GIS is used with spatial data in various applications in hydrology, environmental sciences etc. The spatial data may be combined in a GIS to derive useful information. Various components of a GIS are data encoding, management and manipulation. In data encoding, spatial data are input into a GIS in various forms e.g., raster, vector etc. The various data layers are then stored in the computer. Spatial data are manipulated to derive useful information from them. Various models may be written in a GIS to manipulate the data layers. For an application in flood study, many collateral and remotely sensed data layers are encoded in the GIS. The data layer may be manipulated, output etc. for assessing flood damages.

## 1.2 RIVER PLANFORM

In addition the flood inundation mapping river planform may also be studied from remotely sensed and collateral data. River planform or river configuration is representation of meandering river in alluvium. Various measurements may be done on the river planforms namely river sinuosity, bend statistics. Their definitions are given below:

Sinuosity: It is the ratio of thalweg distance to air line distance or valley length of the river. Sinuosity in meandering rivers is usually more than 1.25. It may be more than even 2 for tortuously meandering rivers.

Loop radius: Loop radius is the radius of the arc fitted to a meander loop.

Loop width: It is the straight line distance between point of inflections of the meander loops.

Arc angle: It is an angle subtended from centre of the arc of a circle fitted to a meander loop between the points of inflection.

Amplitude: Amplitude is maximum height of loop from the line joining point of inflections.

Wave length: Wave length is a straight line distance between equivalent successive points in river meanders.

In the past bend measurements have been reported for large loops. This renders information generated from very early research on river's bend measurement of questionable quality. Standardisation in bend measurements is a difficult task as the loop characteristics may be a function of many factors e.g., river discharge, sediment load, bed and bank material etc. These may change in small river reaches.

## 1.3 FLOODPLAIN FEATURES

Various flood plain deposits are formed by the meandering rivers. These are lateral and vertical accretions, lag deposits, oxbow lakes, channel fillings, sand bars, natural levees etc. They are defined here:

Vertical accretion: These are deposits formed by the bed load of the rivers. An example of this type of deposits is lag deposit.

Lateral accretion: This deposit is formed by suspended sediments. They form only a part of flood plain deposits. It may also be absent in some flood plains.

Lag deposits: They are sorted coarse material left behind in the bed of the river.

Oxbow lakes: The lakes are formed through the cutoff of the meander loops. They are observed very well due to their arcuate shape on remotely sensed data.

Channel fillings (sand and clay plugs): These are deposits made in abandoned meander loops. Sand plugs are formed in the upstream ends of the abandoned channels. The clay plugs are formed by filling up of the cutoff channels.

Sand bars: These are lateral accretion type of the deposits. They are formed at the convex side of a meander loop. The channel bed material deposited here is the cause of their formation. There may be arcuate slough and ridges present in the sand bars. They are also formed at the confluences or in the middle of channels.

Natural levee: These are ridges that run parallel to the river course. They may not be present in some flood plains. The slope is milder in direction away from the river course. They consist of coarser materials and possess good drainage characteristics. They are easy to spot on remotely sensed data. They may be fragmented at times.

Floodplain features are very well mapped from aerial photographs. From satellite data also it is possible to map flood plain deposits specially sand bars and oxbow lakes are very conspicuous on satellite data and are easily mapped.

## 1.4 SATLUJ RIVER

Flood inundation and planform mapping using remotely sensed data is completed for the Satluj basin. The inundation study is done for Sept. 1988 flood. The hydrometeorology of this flood and conveyance capacity of the Satluj channel at a cross-section downstream Roopnagar are described below:

### 1.4.1 Hydrometeorology of Sept. 1988 flood

Cyclonic rainfall occurred in Satluj basin between 24th- 26th Sept. 1988. This has resulted in flooding in the basin. The flood occurred in the Satluj between 23rd-27th Sept. 1988. The rainfall and flood hydrograph/ flood discharge values are given here.

Rainfall: Rainfall mainly concentrated during 3-day period. This was an unprecedented rainfall when three-day cumulative rainfall was taken. The values in the depth-area-duration (DAD) curve are high compared to an earlier 3-day curve. There was a uniform distribution of rainfall in the basin from 3- day rainfall. The centre of the rainfall was located in the Satluj basin at Nawashahr. Here, rainfall on respectively 1, 2 and 3 days was 514, 649 and 714 mm. For 2 and 3 day rainfall total, there were number of high rainfall centres in the basin. The uniform distribution of 3-day rainfall is indicated by the small gradient in the DAD curve.

Antecedent rainfall condition: The monsoon was active in the basin prior to the flood and thus, the antecedent rainfall condition in the basin was wet. Consequently, a high flood was resulted.

Discharge: Outflow data are available on hourly basis at the Bhakra reservoir from 23rd- 27th Sept. 1988. The hydrograph is shown in the Fig. 1.1. There were two peaks of 4144 and 4209 cumec that occurred on 24th at 8 hours and on 26th, 17- 19 hours respectively. For most part of the storm the discharge was above 3000 cumec (Anonymous 1996[1]).

Further downstream at Roopnagar headworks the maximum discharge passed was 13530 cumec. This was more than three fold that from the Bhakra reservoir. This indicates that a large discharge was added by Soan river (516 sq. km.) and the catchment of the Satluj between Bhakra and Roopnagar (on right side of the river, area is 104 sq. km.). At Phillaur gauge discharge site located 75 km downstream from Roopnagar, the computed peak discharge on 25th (R.L. 783.5 feet) using the rating curve is 11801 cumec. This is highest ever discharge occurred at the site.

There were washing-away of embankment and breaches and overtopping of them in the Satluj basin downstream of the Roopnagar. This caused flooding in the floodplain and reduction in the peak discharge at Phillaur as compared to that at Roopnagar headworks (Anonymous 1996[2]).

### 1.4.2 Conveyance capacity

A rating curve is computed at gauge discharge site at Phillaur up to 785.0 feet R.L. The discharge at this R.L. is 14858 cumec. R.L. of the right bank embankment is 787.0 feet. Thus, 2.0 feet freeboard is available at this discharge. For 3 feet freeboard, conveyance capacity is 12763 cumec. The G.D. site is located between a rail bridge (downstream) and a road bridge (upstream). Gauge is located on the old rail-cum-road bridge. At low discharges area-velocity method is used for the discharge measurements (Anonymous 1996[2]).

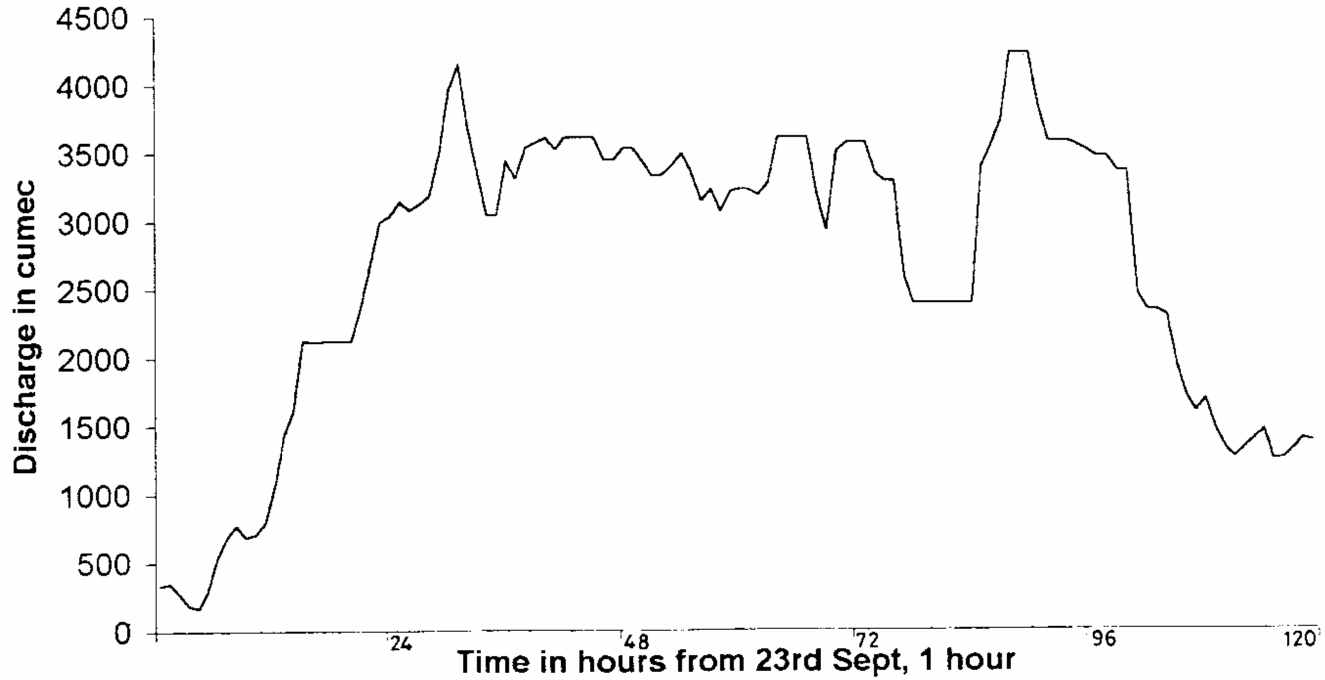


Fig 1.1 Outflow hydrograph 23rd- 27th Sept. 1988 at Bhakra

## 2 LITERATURE SURVEY

Jha (1993) has studied flood inundation in Punpun catchment in Ganga basin, Bihar, India. The area of the catchment is 8530 sq km. The river's confluence with Ganga is located 25 km downstream from Patna. The elevation of the basin varies from 50 to 300 m. Physiographically the catchment consists of Chhotanagpur plateau and plains. Landuse and cover classes are agriculture, forest and other classes (5000, 2500 and 1000 sq km respectively). The rainfall varies from 992 mm to 1335 mm and increases from plains to the plateau. The river is rainfed. Soils in the catchment are alluvial, brown forest soils, red soils, laterites etc. The inundation area is mapped with the help of pre and post monsoon satellite FCC at the scale of 1:250000. The Survey of India (SOI) topographic maps, at the scale of 1:250000 scale, are used as a base map. The maps are verified from the ground truth.

Anil Kumar (1993) has mapped flood inundation in Ganga basin between Aarah and Patna in Bihar. Data used are IRS FCC at a scale of 1:250000 for the months of March and December 1989. The data are visually interpreted and flood plain features, flood inundation, permanently wet areas, wet areas due to flood are mapped. Wet areas (flood) are difficult to discriminate from waterlogged and backswamp areas. The villages affected from flood are also marked from SOI topographic maps.

Chaturvedi and Rajiva Mohan (1983) have studied flooding in Eastern U.P. between Allahabad and Ghazipur using Landsat MSS data for March 1975 and September 1982. The data correspond to large flood events of September 1982. Band 7 (infrared) data are used at a scale of 1:250000. Large tracts in the vicinity of the rivers namely Ganga and it tributaries- Sai, Ghaghara, Rapti are found inundated. An area is mapped where flood has receded in Yamuna. The delineation of the area has been difficult due to similarity in signatures in the area with the waterlogged areas. A pond nearby Sai is also found inundated due to the river flood water. Other ponds are found filled up. The villages affected by flooding are also marked.

Chopra and others (1993) have studied large scale flooding in Punjab, India during July 1993. The state has good surface water resource in form of three major rivers namely Satluj, Beas and Ravi. The rivers receive high runoff during monsoon periods. Satluj- Yamuna link (SYL) canal also augments the water resource in the state. Mean annual minimum temperature in the state is nearly 5°C (January). The rainfall varies from 300 mm to 1400 mm. The mean annual rainfall increases from south-west to the north-east direction. Physiographically the state consists of Shiwalik hills, piedmont, plain, sand, old peleochannels and floodplains. The basin area is also classified as Upper Bari doab, Bist doab, Ghaggar tract and Sirhind tract. Large flood events have occurred in the July 1993 and September 1988. The September 1988 flood event has been studied in the past. Data used are from IRS LISS-1 sensor in the form of FCC at a scale of 1:250000 for the state and ERS data for Fatehgarh, Patiala and Roopnagar districts. Visual interpretation technique is used. Areas are classified as severely flood affected (>50% area flood affected), moderately flood affected (25%-50% area flood affected) and slightly/ non-flood affected. Total flood affected area is 19% (it was 18.3% during September 1988 flood). Severely flood affected districts are Fatehgarh, Patiala, Gurdaspur and Mansa. Fatehgarh and Patiala floods are caused by blockages in SYL canal, breaches in Bhakra, Sirhind canals and blockages of the natural drains by Bhakra canal. Gurdaspur flood is caused by overflow in Ravi and Beas. Mansa flooding is caused by inadequate drainage and the overflowing Ghaggar. Areas in Satluj basin for the Roopnagar district are more affected by the flood than areas in the basin for the other districts. The flooding is caused by breaches in Bunds in Satluj and Budki nala. Breaches in Satluj near Macchiwara, Budha nala near Ludhiana; and Sirhind canal near Khanna have also caused flooding. During the year 1988 there was more flooding in Ludhiana district along Satluj and Budha nala and less flooding in Roopnagar district. Other causes of flooding are overflowing mountain torrents (near Hoshiarpur), poor urban drainage (e.g., in Patiala town), unpreparedness of the authority, absence of a contingency action plan, lack of communication and warning during floods, inadequate drainage for floods of very large magnitude etc.

# 3 STUDY AREA

Satluj is a part of Indus system in north west of India. The river originates at an altitude of 4630m (Anonymous 1980). It enters the state of Punjab near Roopnagar. From Roopnagar it flows in western direction. Near Harike, District Amritsar, Beas joins the Satluj. Mean annual temperature varies from 22.5°C to 25°C. It increases in the south-west. The mean annual rainfall for Nakodar (District Jullundur), Ludhiana, and Roopnagar are respectively 529, 680 and 808 mm. Mean monthly rainfall for July are respectively 145, 196 and 238 mm. Mean monthly rainfall for August are respectively 130, 163 and 217 mm. Most of the rainfall occurs in the months of July to October (Anonymous 1962). Administrative districts in the area are Roopnagar, Hoshiarpur, Ludhiana, Jullundur and Faridkot. Satluj up to confluence of Beas in the State of Punjab is selected for the study of river planform. A part of the river basin from Roopnagar (up to 181 km downstream from Roopnagar) is selected for planform mapping. An upstream reach of 50 km length is studied for flood inundation. Study area location for the planform and inundation mapping is shown in the Fig 3.1 and for inundation mapping only is shown in the Fig. 3.2.

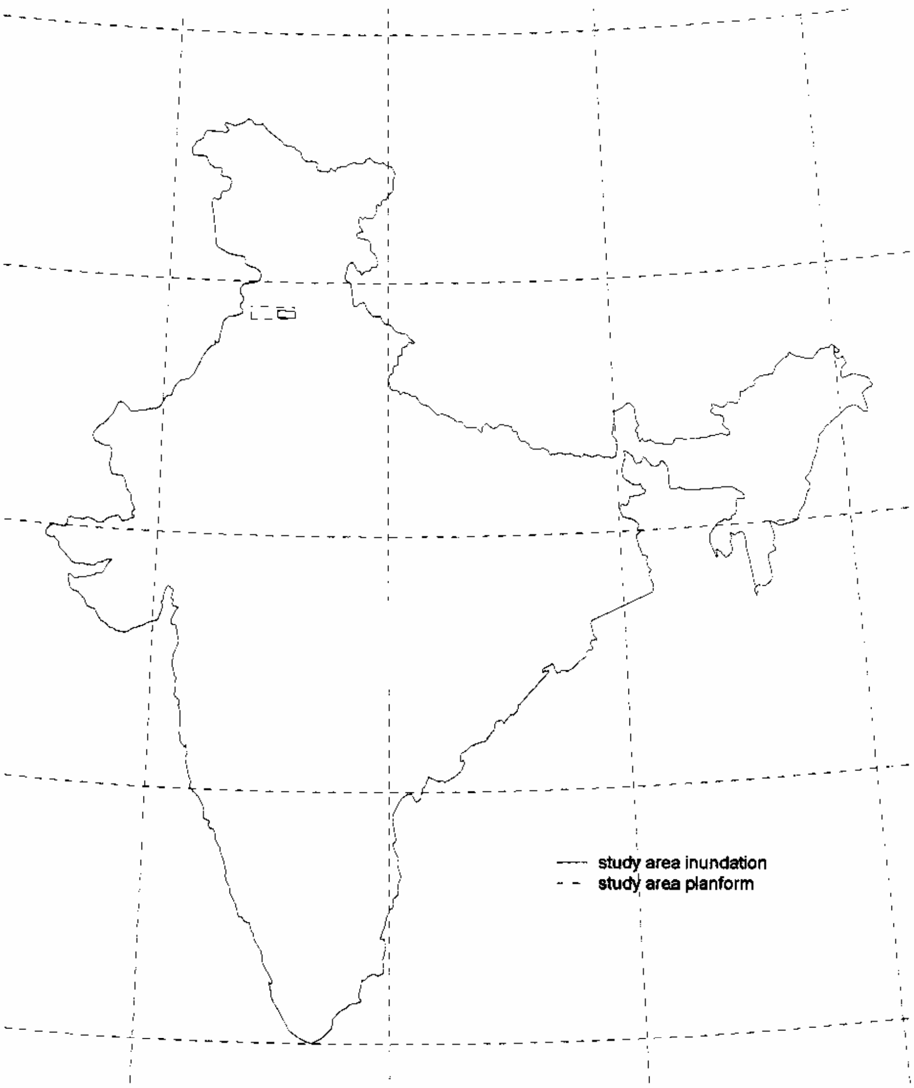


**FIG. 3.1 Study area**

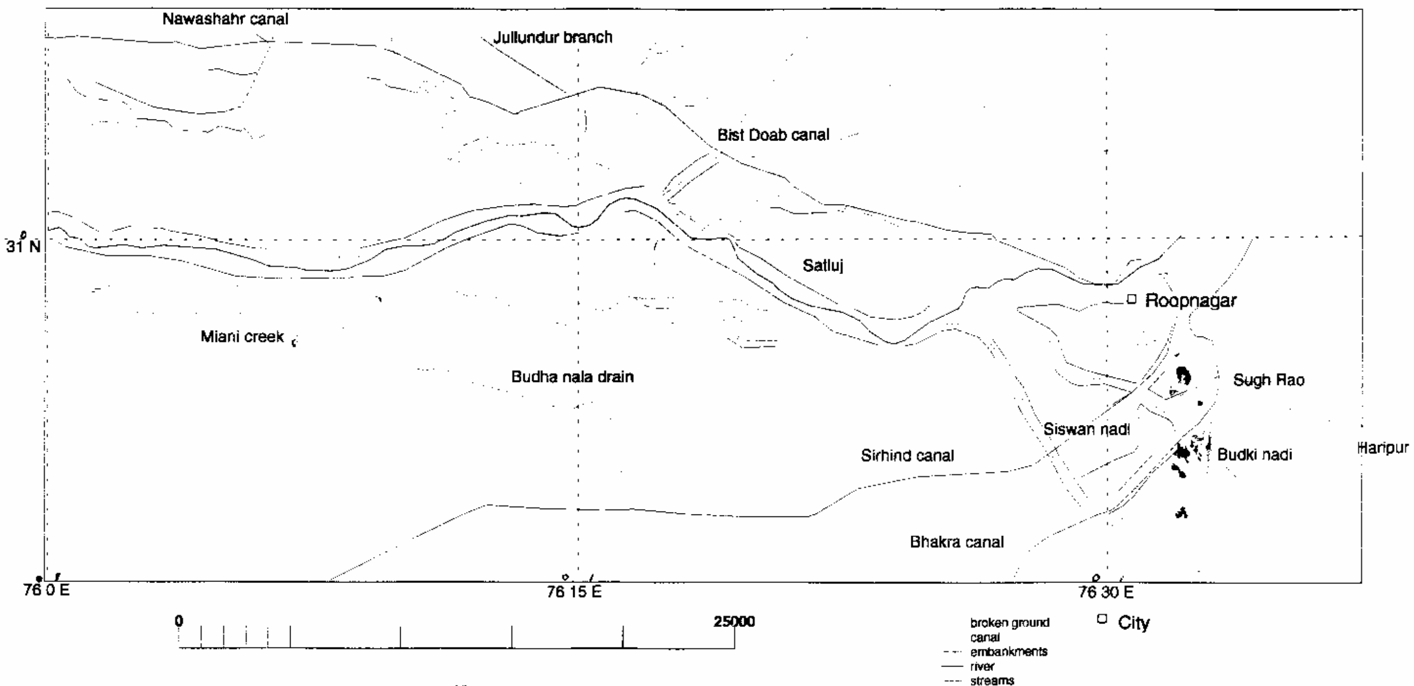


FIG. 3.2 Study area (inundation mapping)

## 4 STATEMENT OF THE PROBLEM

Remote sensing application to surface water inventories is identified as an operational application (Rango 1994). The remotely sensed data in visible and near infra red are found to be very useful in mapping of the water feature due to the fact that water has low spectral reflectance at these wavelengths. This property has been utilised in past to map flood inundation using visual interpretation. The digital image processing e.g., classification has not been utilised in past. Thus, digital classification technique is used here for flood inundation mapping for the Satluj basin, Indus system, Punjab, India. Other than inundation mapping, flood damage assessment, flood plain features mapping and planform study is also completed.

The river has low occurrence of flood due to the construction of Govind Sagar (near Nangal) upstream of the Roopnagar town. In spite of this, large floods do occur e.g., large floods had occurred during September 1988 and July 1993 in the past. Large tracts were inundated during the floods. The September 1988 flood is selected for the inundation study. The peak discharge from the Bhakra dam was on 27.9.88. Cloud free satellite remotely sensed data from IRS were available immediately after the flood. Thus, it was possible to complete this study in flood inundation mapping using digital satellite remotely sensed data.

A flood inundates land adjoining a river course depending upon the discharge, topography, presence of the flood control structures e.g., embankments etc. An exact cause of the occurrence of the flood could be investigated using various available collateral data and maps prepared from remotely sensed data within a GIS. Various map layers may be overlaid for the analysis of the data. Thus a GIS based approach is selected here. The damage due to inundation is dependent on the present land use and cover. Thus, temporal remotely sensed data are needed for preparing land use and cover maps. The damage assessment e.g., to the crop, other damages may be assessed by overlying data from various sources. Two commercial GIS and image processing softwares namely PC ERDAS 7.5 and ILWIS are available and used here.

# 5 DATA AND METHODOLOGY

## 5.1 DATA

Remotely sensed data used are satellite data from IRS satellites in the form of FCC paper prints and digital data for LISS-II sensor. The digital data is used for scene 30-46 A1 for date 1.10.88. FCC paper prints at the scale of 1:250000 are used for scenes 31-46 A1, B1 and 30-46 A1 for dates 11.10.89, 11.10.89 and 15.12.89 respectively. The map is used for plan form study and flood damage assessment. Topographic maps used are 53 A/4,8 and 53 B/1,5,9 at the scale of 1:50000. The topographic maps are used for study of flood inundation for comparing features e.g. embankments, flood channels and terraces. The period of survey for the toposheets is 1964 to 1965. Other than these data, information on occurrence of maximum discharge at Govind Sagar dam, Roopnagar H/W are also known through authorities namely Bhakra Beas Management Board, Nangal township and Office of Chief Engineer, Drainage, Punjab Irrigation Works, Chandigarh.

## 5.2 METHODOLOGY

The satellite and collateral data are used here for flood inundation, flood plain features mapping, planform study and damage assessment due to floods. Remotely sensed data are classified digitally and interpreted to obtain flood inundation, land use and plan form maps. The resulted data are analysed in GIS through map overlay, reclassification operations deriving useful information.

### 5.2.1 DATA PREPARATION

Flood inundation mapping is completed by unsupervised classification of satellite data. The classification is done in PC ERDAS 7.5 software. The satellite data rectification is done in ILWIS 2.1. All the input data in the data preparation are encoded/ rectified to same coordinate system. The map coordinate system used is given below:

| | |
|---|---|
| Geoid | Everest |
| Map datum | Everest 1975 |
| Map projection | Polyconic |
| Central meridian | 76 E |
| False northings | 0 m |
| False eastings | 500000 m |

Rectification: A part of the scene (row 21 to 1490 and columns 151 to 1890) of size 1470 lines and 1740 pixels is extracted from the whole data file. The size of this file is approximately 3361 sq. km. Total 25 GCPs are selected with a RMS error of 1.182 pixels. The data is rectified at 36 m X 36 m pixel size. The size of rectified image is 1566 lines X 1824 pixels.

Sequential clustering: The rectified image is classified using sequential clustering technique. The default parameters in the classification are selected except X and Y skip factors. Value for these is taken as 5 each. Total clusters obtained are 27. The thematic classes for these clusters are identified from the color of the classified data in GIS display and location of the pixels of the clusters.

Classes identified are flood/ river water, water in low lying areas, severely flood affected, flood affected and sand casting. The Colors of the classes in the unsupervised classification are described here. Flood water is blue green. Water in the low lying areas is black. Severely flood affected areas is cyan. Flood affected areas is medium to light cyan. Sand casting area is very bright cyan. Two clusters are obtained for flood water and flood affected area each. For other thematic classes, one cluster is obtained in each class. Severely flood affected category is located near the flood water. Sand casting areas are located at the beginning of flood channels and at the cross drainage works for hill torrents and in the streams etc. Area of the classes i.e., flood/ river water, water in low lying areas, severely flood affected, flood affected and sand casting are respectively 37, 15, 21, 95 and 10 sq. km. The percentage areas are respectively 4, 1.9, 2.3, 10.3 and 1.1. The flood inundation thematic maps prepared for the study area are shown in Fig. 5.1.

**Land use map**

The land use and cover maps are prepared for the area using visual interpretation technique (Fig 5.2). The interpretation key is given in the Table 5.1. Areas and percentage areas for the land use and cover classes are given in the Table 5.2.

The map is rectified in ILWIS by taking GCPs from topographic maps. In all 14 GCPs are selected. The r.m.s. error in rectification is 1.254 pixels at 100 m X 100 m input pixel size. The map is rectified to the pixel size of 36 m X 36 m to facilitate map overlay operations in PC ERDAS. The size of rectified maps is 497 lines X 1433 pixels. The map is used in damage analysis.

**River course**

The river course is mapped for planform analysis of the Satluj. The river reach lies in three scene quadrants of LISS-II. The river course is mapped in three FCC prints and they are joined by taking three photo control points on each print. The river course is digitized in ILWIS by taking the scale of the map as 1:250000 (the scale of the standard processed FCC). The map is printed at this scale. This is used for planform analysis.

From the planform analysis straight reaches are identified. These reaches and the river course map are used for drawing air line or valley direction map. This line is then digitized in ILWIS.

**Planform measurements**

Planform measurements are completed manually from the printed map showing river course. The circular arcs are fitted to the river meander loops. Small deviations of approximately 250 m or less are left out in curve fitting. The loops, with arc angle smaller than 1 radian, are considered straight reaches. The inflection points are marked. The minimum length of a straight reach is considered to be equal to 1 km. The radius, length of loop, arc angle, loop amplitude and wavelength of meanders are measured manually. The least count for arc angle is taken as 5°. The length of the river and air-line distance or the valley length are measured in ILWIS to compute sinuosity. For calculating median values in the measurements, the values are arranged in descending order and middle value is selected from the sorted values. The planform measurements are given in Table 5.3.

**Flood plain features**

Flood plain features namely oxbow lakes, abandoned channels, sand bars, meander scars are mapped from satellite FCC (Fig 5.3). The oxbow lakes are clearly visible due to their shape and color. On December scene the oxbow lake color is black. Lakes in the October scene are mainly red in color. 'Sand bars' are clearly visible. Vegetation is also seen on the 'sand bars'. Abandoned channels have white signature. The flood channels/ old channel in the scene 30-46 A1 (October) has magenta color indicating presence of riverine vegetation. The number and lengths of oxbow lakes are determined in ILWIS. From these values, a median length for oxbow lakes is determined (Table 5.3).

### 5.2.2 ANALYSIS

**Flood damage**

Different land use and cover classes are inundated by the floods. This renders the damage analysis difficult. The maps namely land use and cover and inundation are required to be overlaid for this analysis through GIS modelling operation. GIS operations are described below:

<u>Weight assignment</u>: Maps namely land use and cover and flood inundation are assigned weights in the range of 1 to 10 for their damage causing potential and importance of land. The weights are given in the Table 5.4. The weights are entered as attributes to GIS maps.

<u>Damage assessment</u>: Damage assessment is done by running GIS model on input maps (Formula 1). The output map (Fig 5.4) indicates damage severity in the scale of 1 to 10. For the display, the scale is reversed through GIS analysis.

$$output = A * B/10 \quad (1)$$

Where,

A= inundation weight map

B= land use (next season) weight map

**Table 5.1 Interpretation key (Dec. 1989 scene)**

| Land use/ cover | Elements of interpretation |
|---|---|
| Agriculture | bright red or red with patches of cyan or black color; coarse texture |
| Forest | Magenta color; medium texture |
| Sparse forest | Light magenta with patches of cyan color; medium texture |
| Open land | Cyan or yellowish white color; smooth texture |
| Sand | Bright white; smooth texture; located near the river |

**Table 5.2 Land use classes**

| Land use and cover | December 1989 | |
|---|---|---|
| | Area sq. km. | % area |
| Agriculture | 772 | 83.7 |
| Fallow | 60 | 6.5 |
| Forest | 12 | 1.3 |
| Sparse forest | 8 | 0.9 |
| Open land | 45 | 4.8 |
| Sand | 25 | 2.8 |
| Total | 922 | 100.00 |

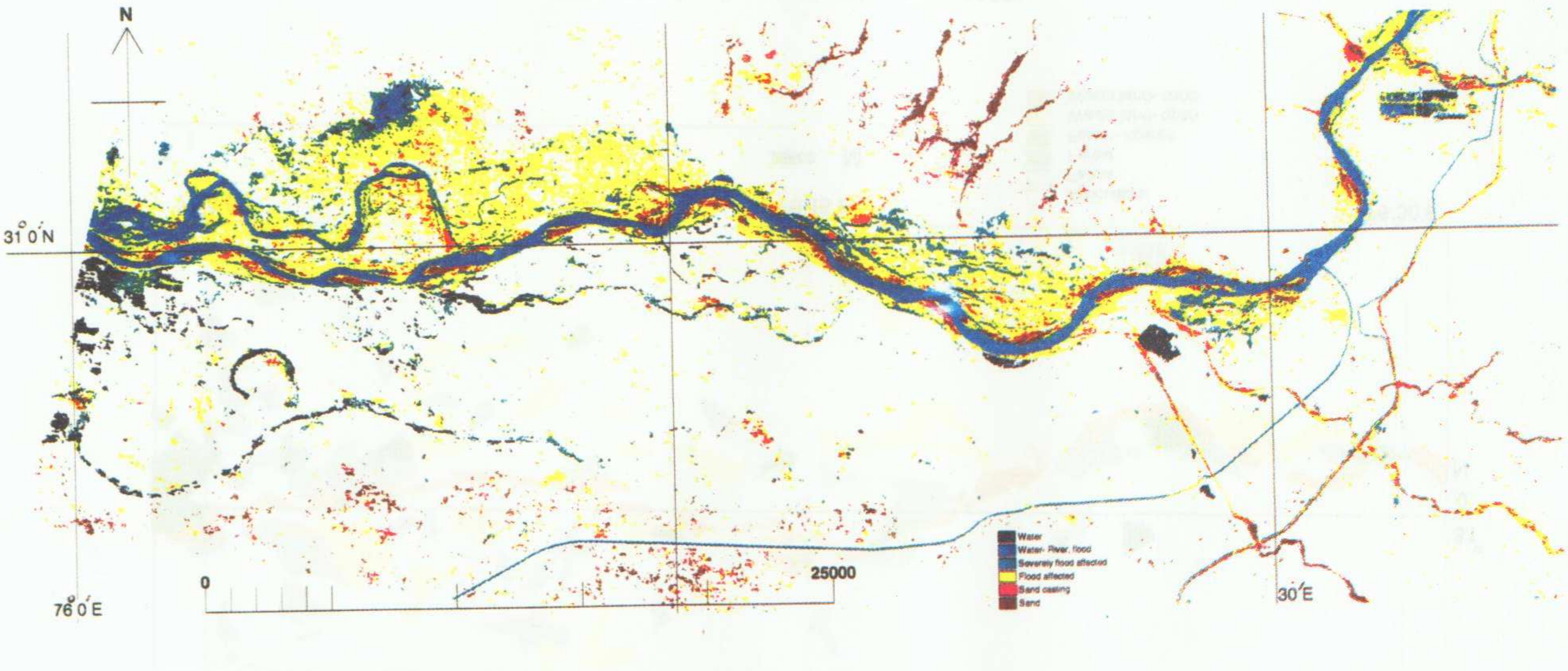


FIG. 5.1 FLOOD AFFECTED/ INUNDATION AREAS (SEPT. 23- 27 1988 FLOOD)

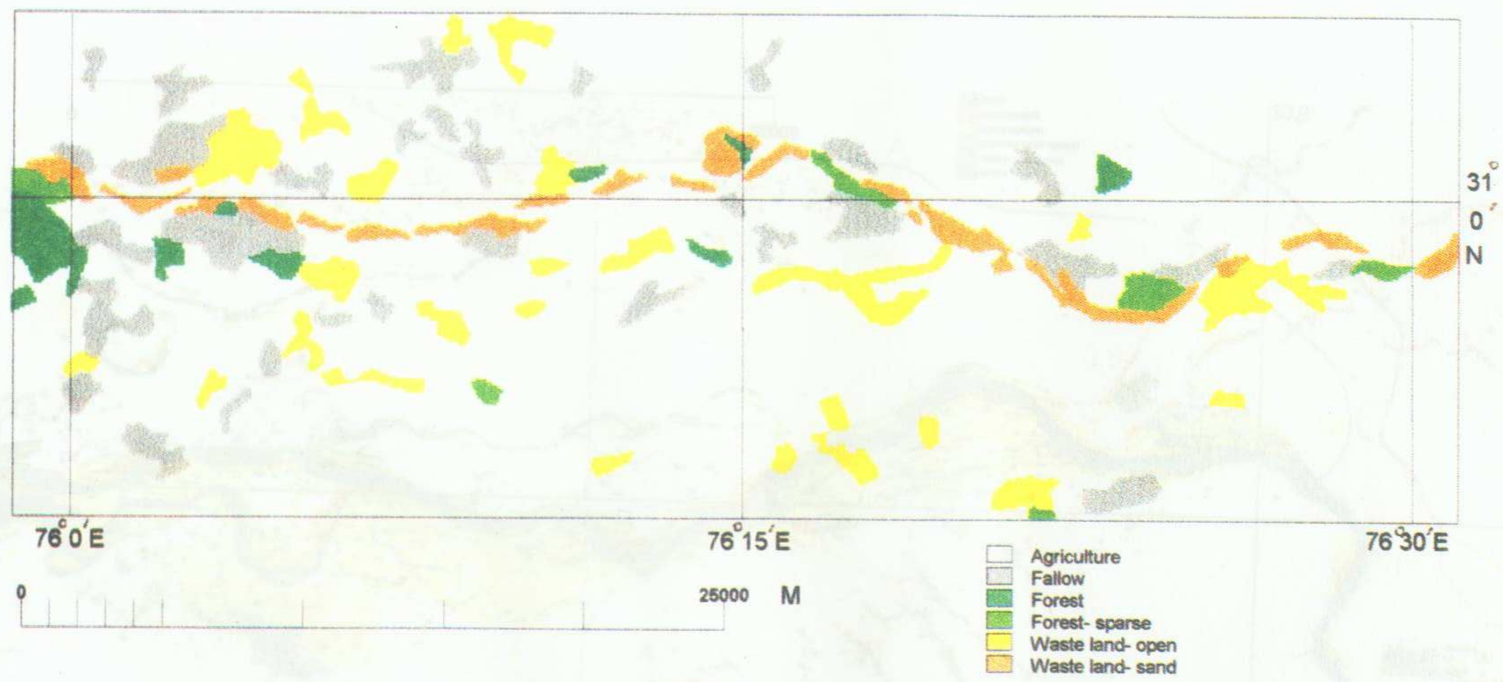


**FIG. 5.2 Land use and cover (Dec. 1989)**

**Table 5.3 Planform measurements**

| | |
|---|---|
| Lengths of the main channel | 181.5 Km |
| Valley lengths | 160.6 Km |
| Sinuosity | 1.13 |
| Median wave length | 4.0 Km |
| Median loop arc angle | 100 |
| Median loop length | 3.5 Km |
| Median loop amplitude | 0.375 Km |
| Median arc radius | 1.25 Km |
| Median length of oxbow lakes | 0.9 km |
| No. of oxbow lakes | 16 |
| Oxbow lake lengths | 0.3 to 4.2 km |
| Total length of oxbow lakes | 17.8 km |

**Table 5.4 Weights for flood damage assessment**

| Land use/ cover | weight | flood inundation | weight |
|---|---|---|---|
| Agriculture/fallow | 10 | River/ swamp | 0 |
| Forest | 2 | Water (low lying area) | 10 |
| Sparse forest | 1 | Severely flood affected | 10 |
| Open land | 1 | Flood affected | 8 |
| Sand | 0 | Sand casting | 10 |

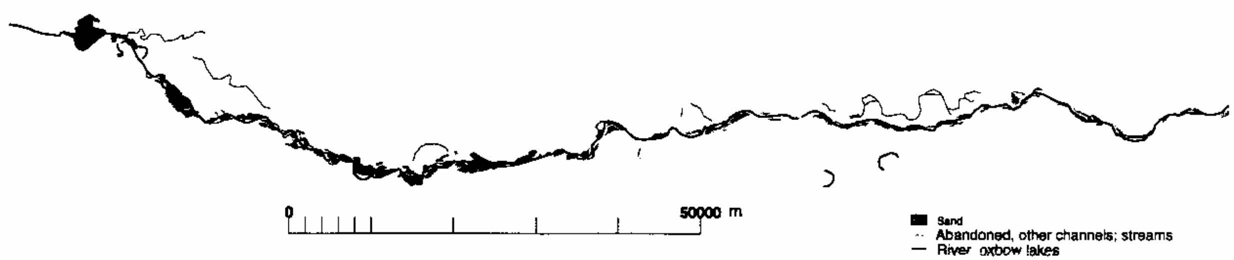


FIG. 5.3 Flood plain features (Year 1989)

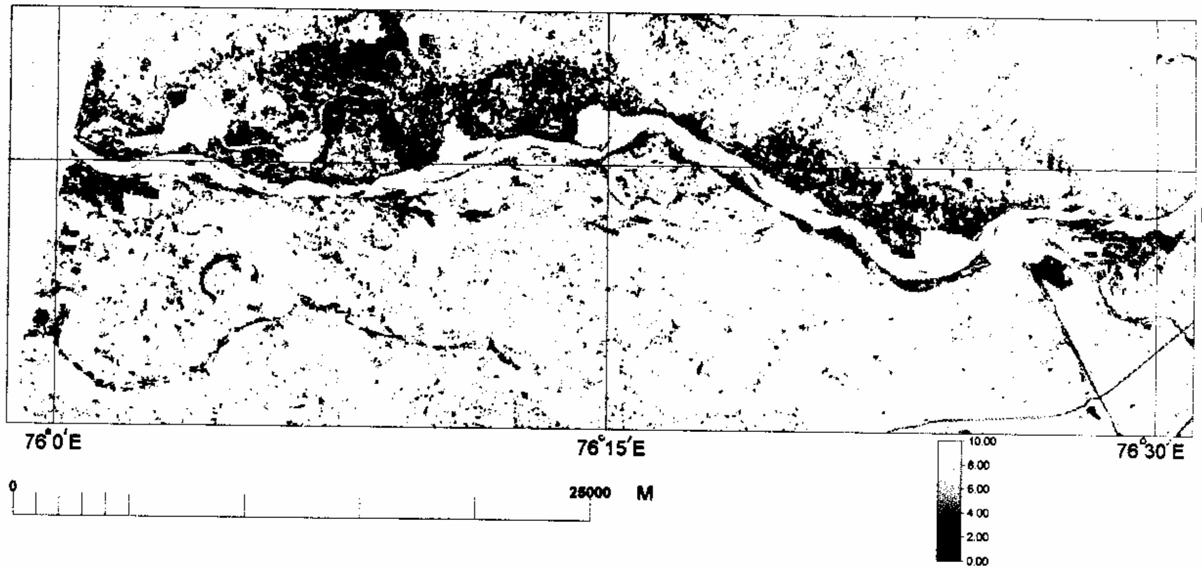


**FIG. 5.4 Flood damage (Sept. 23- 27 1988 flood)**

**(Damage scale 1- 10 in decreasing order of the damage)**

## 6 RESULTS

In this report, three maps are prepared and measurements are performed on the planform. The maps prepared are land use and cover maps from visual interpretation of the satellite data and flood inundation map from the digital classification of the satellite data and flood damage map. Measurements are performed on the meander loops. These results are briefly described here.

**Land use**

The area has mainly agricultural land use in the flood plain. In addition there are some patches of forests in the flood plain and other classes are also observed. The 'grass land' near the river course is not identified on the satellite data. The classes are delineated using a 'minimum mapping unit' of 1 sq. km. Thus, there may be smaller units of other classes within a class. The map depicts 1st order land use and cover in the study area. No accuracy checking and ground truth in the form of field visit is done.

**Flood inundation**

There are possibly two causes of flooding namely flood water spilling from the river and tributaries and rain water getting accumulated in the agricultural fields and low lying areas and plain areas due to poor drainage. This information is derived based on different signature in two classes, their location etc.

There is wide spread flooding mainly on right-bank of the river. Extent of water spread/ flood affected area is seen up to approximately 4 km from the river course on the right flank. On the downstream side there is approximately 3 sq. km. area seen inundated from flood. On the left flank two patches of flood affected and inundation areas are observed. One is located on immediate downstream side of the Sirhind canal takeoff point. This area is approximately 2 sq. km. It is mainly flood-affected area. Another area on the end of the river reach is severely flood affected and is 1 sq. km. approximately. Sand casting is another phenomena observed. There are many small flood channels seen on the right flank of the river. The water from the field/ plain areas, from the river might have flowed in these channels. Effect of the topography can also be seen on the right flank of the river course. Higher elevation areas (shown as broken ground)/ embankments at approximately 76 12 E and 31 05 N coordinates are not inundated due to higher elevation.

There are areas delineated on the right flank of the river that appear to be flooded due to collection of rainwater in the low-lying area. These areas are located at the confluence of the Budki and Siswan nadi and on the right side of the river on the end of the reach. There are many small areas classified as 'water in low lying areas' e.g., oxbow lake and flood channel (on the right flank).

**Damage assessment**

Example of 'low' flood damage areas are those areas located at approximately 76°15'E and 31°00' N; 76°22' E (close to the river course). These areas are situated on the right flank of the river. Areas with flood damage values 1- 3 and 7- 10 (low and high damage classes) are respectively 20 and 110 sq. km. Damage areas are mainly located on the right flank of the river.

The damage assessment is of preliminary nature only. The 'high flood damage' class includes crop and fallow land, since the crop area map of the flood season for the year under investigation is not used. Further, the maps superimposed are prepared from two different techniques namely digital analysis and visual interpretation. They differ in minimum mapping units. This results in little inaccuracy on the overlay analysis. The results may help in further analysis and collection of the information/ data etc.

**Planform properties**

The planform measurements are for the normal stage in the river. There is some amount of subjectivity introduced in curve fitting during planform measurements. In spite of this, the measurements provide an indication on the order of discharges in the river. These will help in establishing relationships between discharge and the measurements when the values are available for many rivers of different sizes and for the same river at different river stages.

# 7 CONCLUSIONS

1. The area with low and high flood damage are respectively 20 and 110 sq. km. The percentage areas of these classes are respectively 2.2 and 11.9. The agricultural area is nearly 90% in the study area.
2. This causes occurrence of larger area under 'high damage' class than other damage classes. The causes of the flood are over topping, washing away and breaches in the embankments, synchronisation of floods in the Satluj and the hill torrents and occurrence of low lying areas with poor drainage.
3. Flooding has occurred predominantly on right flank of the river up to the Bist Doab and Nawhashar canals. High elevation areas/ broken ground regions are not flooded on the right flank. On the left flank also flooding has occurred. Hill torrents also cause sand casting. Thus, flood susceptible areas are demarcated here. In the light of these findings suitable flood protection, warning system may be planned for the flood susceptible areas.
4. The river is canalised downstream of the Roopnagar headworks. The approximate width of the canalised sections varies from 1 to 1.5 km. It leaves little space for free river meandering and causes erosion of embankments by the meandering river. Further, the conveyance capacity of the canalised river is also low. Thus discharge larger than 12000 cumecs causes damages to the embankments causing floods. Since the embankments are already constructed, there is need for a comprehensive review of the whole issue of the flooding in the basin. Possible solutions e.g. retiring embankments and construction of new embankments in due course of time, considering the river morphology in proper perspective for designing embankments, applying flood control measures that are successful in other basins etc. should be taken up. Remotely sensed data will provide information on vulnerable section by plotting planform and inundation etc.
5. A preliminary idea of flood damage is obtained through the GIS analysis of maps from remotely sensed data. This will be useful to field personnel to locate the damage areas.
6. The inundation map is prepared from digital image processing. Thus the minimum mapping unit here is equal to the pixel size of the digital data. The information/ map thus derived is more detailed and will be more useful to the field personnel.
7. Proper flood control measures may be planned using the maps in the form of construction of embankments, land use planning, establishing a flood warning system etc. This will be needed especially on the right flank of the river.
8. There are not many oxbow lakes visible in the data. This indicates that the river meander migrations are not very frequent in this basin especially in the upper reach of the river.

## REFERENCES


Anil Kumar (1993), 'Flood damage assessment in the area of the Ganga confluence with Ghaghara, Gandak and Sone', in 'Proceedings of National Symposium on Remote Sensing Applications for Resources Management with special emphasis on North Eastern region', Guwahati, Nov 25-27, 1993, Indian Society of Remote Sensing, Dehradun, India, pp 46-49.

Anonymous (1962), 'Monthly and annual normals of rainfall and numbers of rainy-days based on record of 1901-1950- Memoirs of India Meteorology Department-Vol XXXI, Part III', India Meteorological Department, New Delhi.

Anonymous (1980), 'Rashtriya Barh Ayog (National Commission on Flood) Report-Vol 1', Ministry of Energy and Irrigation (Department of Irrigation), Government of India, New Delhi, 372p.

Anonymous (1996)[1] 'Operation of Bhakra and Pong reservoirs during flood and other flood mitigation measures- Final report Volume- 1', Water and Power Consultancy Services (India) Ltd., New Delhi, Paging various.

Anonymous (1996)[2] 'Operation of Bhakra and Pong reservoirs during flood and other flood mitigation measures- Final report Volume- 2', Water and Power Consultancy Services (India) Ltd., New Delhi, Paging various.

Chaturvedi R.S., Rajiva Mohan (1983), 'Delineating flood affected areas of South Uttar Pradesh using remote sensing technique', in 'Proceedings of National Symposium on Remote Sensing in Development and Management of Water Resources', Indian Society of Remote Sensing, Dehradun, India, pp 79-87.

Chopra R., V.K. Verma, A. Thomas, P.K. Sharma (1993), 'Extent and causes of floods in Punjab during July 1993- a remote sensing approach', in 'Proceedings of National Symposium on Remote Sensing Applications for Resources Management with special emphasis on North Eastern region', Guwahati, Nov 25-27, 1993, Indian Society of Remote Sensing, Dehradun, India, pp 36-45

Jha R. (1993), 'Flood boundary delineation of Punpun catchment, Bihar using Landsat data', in 'Proceedings of National Symposium on Remote Sensing Applications for Resources Management with special emphasis on North Eastern region', Guwahati, Nov 25-27, 1993, Indian Society of Remote Sensing, Dehradun, India, pp 50-56.

Rango A. (1994), 'Application of remote sensing methods to hydrology and water resources', Hydrological Sciences Journal, Vol 39(4), pp 309-321.

DIRECTOR: DR K. S. RAMASASTRI

DIVISIONAL HEAD: DR A.K. BHAR

STUDY GROUP:

MR D.S. RATHORE