GENERAL GUIDELINES
FOR
PREPARING RIVER MORPHOLOGICAL REPORTS

GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
CENTRAL WATER COMMISSION

NEW DELHI
MARCH, 2009

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FOREWORD

Empirical or semi-empirical approaches guide, to a large extent, the processes involved in planning, design and construction practices in respect of river management in general and river training and anti erosion works in particular. There are instances where indiscriminate adoption of these methods without due regard to the unique characteristics of a river have resulted in performance deficiency or ineffective performance. The situation leads to huge recurring expenditure year after year on the repairs and maintenance of these works. An urgent need thus exists for evolving more rational and scientific approach in planning, design and construction of river management works considering the unique characteristics of each problematic river. These characteristics may be assessed through detailed morphological study of the river.

Many State Government departments and other agencies involved in river management have shown interest in pursuing such studies and some have already initiated action in this direction. Remote Sensing Techniques are capable of providing large information in time and space. The field survey data and remote sensing data may be helpful in hydraulic modelling, both physical and mathematical. Different indices are required to study the meandering and braiding reaches of the river. In order to ensure that a rational pattern is adopted for preparation of river morphological reports by different agencies and to incorporate the advanced technology in computations, especially remote sensing, it has been considered necessary to review and revise the "General Guidelines for Preparing River Morphological Reports", prepared in April, 1991. This publication is an endeavour in that direction and contains revised guidelines.

It should, however, be appreciated that considering the constraints and complexity of understanding the river behaviour, these guidelines cannot be comprehensive and universal. Specific river problems and river characteristics will obviously dictate the final contents of a morphological report. Despite the inherent limitations, I hope this publication will be found quite handy for experts in the field and go a long way in providing an insight into the basic objectives and requirements of such reports.

(A. K. BAJAJ)
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CENTRAL WATER COMMISSION

PREFACE

Since independence a large number of developmental and protective works have been taken up in different river basins all over the country. The developmental works include construction of irrigation, hydro-power, multipurpose water resources projects and navigation works. The protective works include flood embankments, marginal embankments, channel improvements and anti-erosion works like spurs, revetments, bank pitching etc. Most of the protective works have been taken up on rivers of the Ganga and Brahmaputra river systems where the problem of river instability and consequent bank erosion are particularly severe.

It is being increasingly realized that the morphological study of river needs to be properly documented and analyzed and the unique characteristics of each river should be understood so that the responses of the river due to any encroachment in the flood plain and more in the case of future man-made structures may be anticipated and preventive measures as considered necessary may be planned before hand.

Remote Sensing is the technique of collecting information about earth's feature without being in physical contact with it. Remote Sensing Techniques are capable of providing large information in time and space. Aerial photographs and satellite images can provide an extremely powerful means of detecting the clues, as to where and how the river migrated, for the delineation and reconstruction of the river course. Temporal satellite data may be used to study the erosion and deposition characteristics. The field survey data and remote sensing data may be helpful in calibration/validation of hydraulic/mathematical models like MIKE-21C, ANN model, etc. Thus it is required to incorporate the application of Remote Sensing Techniques in the guidelines for morphological studies. It is also desirable to have uniformity in scientific data collection and methodology for morphological studies.

In view of above, it was felt necessary that general guidelines prepared in April, 1991 are reviewed and updated. This revised publication has been accomplished, considering the technical advancements in the field, under the guidance of the 'Standing Committee for Morphological Studies of Himalayan Rivers of India', in which experts from MoWR, CWC, GFCC, Brahmaputra Board, CWPRS, NIH, NRSA, SAC Ahmedabad, GSI, IWAI, Water Resources/ Irrigation departments and SAC of concerned State Governments are represented. Various parameters like Tortuosity and Sinuosity giving idea of meandering characters have been included in the present guidelines. Different braiding indices such as Plan Form Index, Flow Geometry Index, Cross Slope, which may be studied to determine the character of the rivers, have also been included. It is hoped that the publication would be useful to the agencies involved in data collection and morphological studies.

Revision of these guidelines would not have been possible but for the untiring and dedicated efforts of team of officers led by Chief Engineer (P&D) with support from staff of Morphology Directorate, CWC. Valuable contributions of the members of the Standing Committee in revision of the guidelines and the contribution of Dr. Nayan Sharma, Professor, Water Resources Development & Management, IIT, Roorkee, for quantitative description of braiding phenomena of rivers, are duly acknowledged.

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CONTENTS

GENERAL GUIDELINES FOR PREPARING RIVER MORPHOLOGICAL REPORTS

1.0 INTRODUCTION

India, with a vast area of 329 million hectare, has diverse geographic and climatic conditions which results in uneven distribution of rainfall over the country, both in time and space. The rainfall is seasonal and uneven over large party of the country. Most of the rainfall takes place during the monsoon season and the rest of the year remains dry. The large variation in rainfall, which is the main source of water in the rivers, results in large variation of flows in rivers. Due to large variation of flows, the alluvial rivers of the country, such as Ganga and Brahmaputra, have large variation in their behaviour during the lean season and the flood season. While during the lean season, the shoals in the low water channels cause problems in navigation, during flood season, the deep channels swing laterally and erode the banks posing threat of serious damage to valuable property, lines of communication, towns and villages.

The planning, design and construction practices in respect of river training and anti-erosion works at present in vogue in the country are based on empirical or semi-empirical formulae developed towards the end of the Nineteenth Century. Most of these formulae were evolved in connection with the design of irrigation head works and canals. Indiscriminate use of such formulae, without regard to the unique characteristics of a river, sometimes lead to an anomalous situation where the benefits from a river training work are to some extent off-set by its ill-effects on the river regime.

For a scientific and rational approach to different river problems and proper planning and design of water resources projects, an understanding of the morphology and behaviour of the river is a pre-requisite. Morphology (of river) is a field of science which deals with the change of river plan form and cross sections due to sedimentation and erosion. In this field, dynamics of flow and sediment transport are the principal elements. The Morphological Studies, therefore, play an important role in planning, designing and maintaining river engineering structures. In recent years, there has been a growing awareness about the need for taking up Morphological Study of rivers in the country, especially with particular reference to their unique problems. In order to assist the engineers of the concerned departments and other agencies, broad guidelines are prepared for preparation of Morphological Study Reports.

2.0 GENERAL APPROACH

2.1 OBJECTIVES

The objectives of river Morphological report are:-

i) To identify the problems - location specific and morphological, works taken up and their performance.

ii) Interpretation of factors responsible for different type of problems, causes of failure of the measures taken and the necessary corrective measures.

iii) Understanding of river mechanics to facilitate mathematical/ hydraulic modelling.
iv) To identify further studies to be carried out.
v) To identify additional data required.
vi) To evolve criteria for planning and design of structures for efficient river management.

2.2 CONTENTS

The contents of a Morphological report are given in Annex I. The specific information to be included in each Chapter is given in Annex II.

3.0 APPRAISAL OF THE PROBLEMS

3.1 PURPOSE

A detailed description of the problem, both location specific, reach specific or over entire system is a basic requirement as this would lead to a choice of the proper methodology for study and identification of the requisite data. The typical problems which are normally encountered in river management are those arising out of natural causes or those caused by man made structures or encroachments into the river bed. These may be one or more of the following:-

(a) NATURAL PROBLEMS

i) Frequent changes in river course.
ii) Avulsion of one river into another (beheading).
iii) Heavy shoal formation (as in Brahmaputra river) causing diversion of the main current towards the banks.
iv) Development of natural cut-off in meandering rivers. This, some times, changes the meandering pattern.
v) Heavy landslides in the catchment causing sudden and steep rise in silt load. This causes instability, as was witnessed in the river Kosi in 1934.
vi) Heavy aggradation of the river bed. This causes high flood levels resulting in overtopping of banks/embankments even during floods of relatively moderate intensity.
vii) Heavy erosion of banks by hill streams due to flash floods (as in West Bengal where large tracts of tea gardens are affected).
viii) River instability due to changes in bed slopes as a result of seismic activity (as in many rivers in Assam).
ix) Changes in river channels due to changes in rainfall pattern.
x) Erratic behaviour of rivers in deltaic areas where they have numerous spill channels.
xi) Erratic behaviour of braided rivers.
xii) Navigational problems due to shoal formations.
xiii) Formation of sand bars at river out-falls into sea, due to reduction in upland discharges as in Hoogly River.
xiv) Morphological changes in a river due to changes in its base level i.e. the levels of the out-fall into another river or sea.

Erosion and deposition at river bends

River Dhansiri at Golaghat (Assam)

Embankment erosion and breach

River Brahmaputra near Guwahati

b) MAN MADE PROBLEMS

i) Degradation of river bed downstream of a dam or a barrage.
ii) Effects of constriction of river width due to barrage/bridge construction.
iii) Effects of flood embankment on the regime of rivers.
iv) Effects of extraction of sand and boulders from the river beds and banks.
v) Effects of spurs and bed bars of different types on river behaviour.
vi) Effects of inter-basin transfers of water on the regime of rivers.
vii) Effects of river bed cultivation and construction by farmers in a river reach.
viii) Effects of dredging/channelisation of river bed. (This is usually done near big cities to keep deep channel near Power House or Water Works).
ix) Effects of pucca bathing ghats in big cities and places of pilgrimage.
x) Effects of heavy urbanization along the river banks.

3.2 APPRAISAL OF MEASURES TAKEN

A detailed account of different measures along with sketches/drawings of structures constructed, basic design criteria and design conditions considered etc. is given. Performance of the existing works is given with the details of the extent and type of failure, if any, noticed from time to time. These details are likely to lead to an understanding of the possible causes of malfunctioning/failure of the work which, in turn, would dictate the choice of morphological parameters to be studied in detail.

4.0 DATA REQUIREMENT

The data requirement would depend primarily on the morphological parameters that are to be studied for a particular river. However, following minimum data is required:

i) Topographical data such as topographical maps, aerial photographs, satellite imageries etc.
ii) River cross-sections up to the highest recorded water level for different years at /in:

- Existing gauge discharge sites (pre-monsoon and post-monsoon).

- The reaches affected by bank erosion and/or erratic river behaviour.

iii) Daily discharge data for the existing discharge observation sites.
iv) Daily gauge data for the existing sites as well as for the study reaches.
v) Daily sediment load data for the existing sites.
vi) Grain size distribution of the bed material for existing sites as well as for study reaches.
vii) Hydrographic charts in the vicinity of the existing sites and in the study reaches.
viii) Grain size distribution of the suspended load and bed load.
ix) Vertical velocity and sediment load distribution at the existing sites.
x) Dimensions of the dunes and/ or ripples.
xi) Geo-morphological map of the basin with particular reference to the flood plain and deltaic plain.

5.0 HISTORICAL PERSPECTIVE

5.1 MORPHOLOGICAL TIME SCALE:

Various flow and channel parameters are interdependent. Identification of independent and dependent variables is an important step in a scientific study of river morphology.

Viewed in a geological time scale of millions of years, a river is an open channel system undergoing continuous changes and there are no definite relations between different parameters as they change with time. On the other hand, over a small time scale of a few days or weeks, a river may be in a 'steady state' in which no significant change in channel characteristics occur. The cause - effect relationship in the two cases may be quite different, which if documented quantitatively may be a source of serious error in the interpretation of the mechanics of river flow and thereby, in the understanding of the river behaviour.

In the graded time span, arbitrarily defined as a few hundred years, a graded condition or a dynamic equilibrium exists. During this time span, the variables which appear as constantly changing in 'geologic time' and as static in 'steady time' appear to fluctuate in a cyclic manner. Geology, hydrology, initial relief and valley dimensions may be considered as 'independent variables' and the channel morphology as 'dependent variable'. It is this time span which is of relevance to the river engineer. In river morphological studies, therefore, these inter-dependencies have to be kept in view.

Since the river channel is the result of flowing water, magnitude and frequency of run-off events are major factors in determining the character of the river channel. It is, therefore, possible to show qualitative relationships between river flow on one hand and different aspects of channel morphology like channel dimensions, shape, gradient etc. on the other.

For a short term (steady-time) evaluation of changes in river parameters, the variables are considered as follows:-

Water discharge	-	Dependent variable.
Sediment discharge	-	Dependent variable.
Hydraulics of flow	-	Dependent variable.
Channel morphology	-	Independent variable.

For the evaluation of parameters in the graded time scale, the variables are as follows:-

Hydrology (mean discharge of water and sediment)	-	Independent variable.
Hydraulics of flow	-	Indeterminate
Channel morphology	-	Dependent variable

6.0 MORPHOLOGICAL STUDIES

6.1 IDENTIFICATION OF REACHES

After detailed appraisal of the problems, the river reaches to be studied are identified and sub-divided into a number of study reaches such that a precise profile of the energy line may be established for the study. Rigid criteria for the length of a reach obviously can not be laid down, but as a general rule, length of about 10 km is considered adequate. In meandering reaches, the study reaches are so demarcated as to identify the curved and straight portions. Braided reaches of the river are sub divided in such a way that all major and minor channels separated by shoals and bars are covered for study. Divided flow (twin channels) and long straight reaches are included in separate study reaches. Estuarine reaches needs to be treated separately especially when the flow is bi-directional.

6.1.1 DEMARCATION OF CROSS SECTION LINES

In each study reach, cross-sections are laid out normal to the direction of flow at an interval of about 5 km distance being measured along the centre line of the main channel.

6.2 DATA COLLECTION

6.2.1 FIELD SURVEY DATA

While para 4.0 gives the data requirement, following data is necessary for specific morphological studies. Some of the data is, therefore, common.

(i) Daily gauge, discharge and sediment data are collected for each Gauge and Discharge (G&D) site in accordance with the procedures laid down in the relevant codes of the Bureau of Indian Standards (BIS). Daily gauges are observed for each study reach. For morphological study, sediment samples are taken from each segment used in discharge measurements.

(ii) Cross sections of the river at the identified locations are taken every year before and after the monsoon season.

(iii) Hydrographic survey of each study reach is done separately for different river stages. The survey charts are used for bed form studies.

(iv) Bathymetric survey data, velocity profiles, water surface slopes, longitudinal profiles etc. should be carried out.

(v) Measurements of the dimensions of the dunes in different parts of the river bed are also made for sediment transport modelling.

(vi) Grain size distribution of the suspended sediment load is determined.

(vii) Grain size distribution of the bed material is also determined.

(viii) Vertical velocity distribution and vertical sediment distribution at significant river stages are observed for each G&D site.

(ix) Engineering properties along with sedimentological studies (both physical and laboratory oriented) of the river bank materials are determined, especially for locations susceptible to river bank erosion/failure/collapse.

(x) Geomorphological map, covering the flood plain and showing important features like point bars, alternate bars, middle bars, ox-bow lakes, palaeo channels, channel plugs etc. should be prepared.

6.2.2 REMOTE SENSING DATA

Satellite imageries play vital role in monitoring the changes of rivers in study reach. Remote sensing data helps in studying inaccessible areas. Remote Sensing data like satellite imageries, digital satellite data (microwave data -Radar sat (Canada data)). Field survey data and remote sensing data may be needed in hydraulic /mathematical models like MIKE-21C, ANN Model etc.

6.3 MORPHOLOGICAL ASPECTS FOR STUDY

6.3.1 RIVER FLOW ANALYSIS

The main objectives of the river flow information are (a) the study and description of river morphology, (b) investigation of river bed forms, (c) study and prediction of sediment transport and (d) analysis of aggradation and degradation. These groups of river mechanics problems are mutually inter-related processes dependent on the river flow processes. Therefore, river flow data is analyzed, described and presented in such a way as to provide the best insight into effects on the various dependent processes.

Many variables in river mechanics are power functions of discharge. Greater values of the exponent in the relationship indicate that high river flows are more important and neglecting the low flows is justified in the study of a particular river problem. Some variables depend on the integrated effect of previous discharges, both low and high, so that all flows are relevant in the study, while some other variables depend not only on the discharge but also on the rate of its variation.

Field survey data and remote sensing data may be needed in hydraulic /mathematical models like MIKE-21C, ANN Model etc. Analysis of Temporal Satellite Data while asserting the history of river course is necessary.

In order to understand the significance of different variables in river mechanics, and to identify the different types mentioned above, structural analysis of the flow series is carried out.

6.3.2 FLUVIAL GEOMORPHOLOGY

For a proper understanding of the processes of erosion and silting on which the morphology of the river depends, it is also necessary to view the fluvial landscape in a historical perspective. The variables influencing the river channels and river system can be broadly categorized as (a) Structure (b) Stage and (c) Process.

(a) STRUCTURE

The term structure as used in geomorphology implies not only the effects of various kind of rocks, but also the differential erosional character of the rocks, the influence of various geologic factors like fractures, joints, faults and their distribution in a drainage basin.

(b) STAGE

The change of landform with time is referred to as stage of development of landform. The progression of erosion in a given region is marked by "Competition" between river systems for drainage area. The most aggressive river with the steepest slope or greatest discharge or an advantage of lower altitude may capture the drainage area of another river system, thereby, changing the course of the latter. The qualitative understanding of this aspect helps in undertaking the detailed investigations of specific problems of avulsion of one river into another.

Landform development is studied from hypsometry curve for the basin drawn between h/H and a/A where 'h' is the contour height above base plane, 'H' is the total height, 'a' is the area enclosed by a given contour and 'A' is the total area of the basin. A typical hypsometric curve shows the lines corresponding to the different stages of development of landform viz. youthful, mature and old stage. Relations between contour height & area and between contour height & percent area above the contour could also be developed. These studies afford a preliminary knowledge of the basin which helps in deciding the further exploratory work in the field. For instance, it would be worthwhile looking for old courses (palaeo channels) of a river in a landform that has reached the old stage.

Drainage pattern of a basin gives a fair idea about the geology of the basin i.e. the nature of rocks, faults, joints, folds, fractures, unconformities etc.

Drainage density, expressed as the length of drainage channels per unit area of the basin helps in better interpretation of the hydrological data of a river. It also helps in identifying different categories of lands, for instance:-

	Drainage density		
Sand stone areas	3	to	4
Fractured igneous rocks	15	to	25
Bad lands	200	to	400

Other basin characteristics like form factor, circular ratio, elongation ratio, bifurcation ratio, stream order etc. are required to be discussed.

(c) PROCESS

Distinctive characteristics of river flow are the "processes" which determine the character of a river channel. River flows in the form of daily discharge, gauge and sediment load, being the most pertinent time series, should be analyzed. This may be done by developing relationships between the three parameters and identifying the unique characteristics of the flow series. On the Yellow River in China, it has been shown that channel shifting varies with fluctuations in discharge, similar to Kosi river in India. A linear relation was found to exist between ratio between maximum discharge to bank full discharge and the wandering intensity in meters / day of the Thalweg.

The "Structure", "Stage" and "Process" aspects of the river morphology afford a qualitative understanding of the nature of a river and its behaviour.

6.3.3 CHANNEL CHARACTERISTICS

Lateral and vertical movement of thalweg at different locations in an alluvial river from year to year is described both in qualitative and quantitative terms from the study of river cross sections. The lateral/ vertical movements of the river bed, where possible, are co-related with the problem of bank erosion/collapse, if any. The description of secondary channels, especially those frequently shifting and causing significant changes in flow pattern near the banks are described.

(a) BANK FULL WIDTH

Bank full width is a subjective term. This is taken as the river width at water surface level corresponding to the dominant discharge or bank full discharge. This could also be decided by the visual examination of the river cross sections and confirmed with the study of gauge and discharge curve plotted on semi-log paper (the level at which the curve flattens out could be taken as the bank level).

Mean Depth (D) = Area of cross section at bank full stage (A) / Bank full width (B)

Width Depth Ratio = B/D.

It is also useful to study changes in channel parameters in the downstream direction for different frequencies of flow.

(b) REGIME STATUS

From the regime formulae of Lacey, width, depth, area and velocity are worked out and these are compared with the observed values at different river stages. Such a study would indicate the applicability or otherwise of the regime formulae of Lacey.

(c) RIVER BED CHARACTERISTICS

i) The qualitative and quantitative descriptions of lateral slope of the flood plain are given from the observed cross sections for different years.

ii) Aggradation and degradation of the river bed in a reach are studied through a comparative study of river cross-sections for different years. These cross-sections for different years are superimposed and the area of each cross-section below a reference line is worked out. An increase in the area from one year to another would indicate degradation while a decrease in area would indicate aggradation at the site.

Aggradation and degradation of the bed may also be reflected in a shift in the G-D curve over a given period. For a meaningful study, it would be desirable to draw G-D curves separately for rising and falling stages of the river.

The above study from cross-sections and G-D curve would indicate aggradation/ degradation at a particular cross-section and not in a reach. However, such a trend between two sites could be broadly studied through a sediment balance study for the reach.

(d) SEDIMENT TRANSPORT

Though there are numerous sediment transport formulae developed by various investigators from time to time, none of these is considered suitable for all situations. Efforts are, therefore, made to develop relationships between observed values of sediment transport on one hand and different flow parameters on the other. The different flow parameters could be discharge, velocity and stream power.

(e) FLOW CHARACTERISTICS

Relations could be developed by plotting graphs on log – log scale between width, depth and velocity on one hand and discharge on the other. For low flows, critical velocity may be co-related with depth to develop an equation which will have the form of Kennedy's equation.

(f) PLAN FORM

Shape of river in plan is very important in many design problems concerning location of bridges etc. In general, the plan forms of alluvial rivers can be classified as (i) Braided, (ii) Straight and (iii) Meandering. Meandering and braiding reaches of the river are separately studied. For meandering reaches, following relations may be developed on log - log scale:-

Meander length (also called wavelength)	Vs.	Bank full width
Meander width	Vs.	Bank full width
Radius of curvature	Vs.	Bank full width

Tortuosity, Sinuosity etc. of the river may be studied.

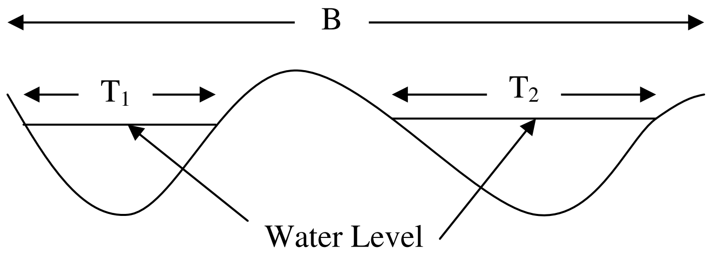
$$\text{Tortuosity} = \frac{\text{Thalweg length - Valley length}}{\text{Valley length}} \times 100$$

$$\text{Sinuosity} = \frac{\text{Thalweg length}}{\text{Valley length}} \times 100$$

For a more logical and quantitative description of braiding phenomena, following indices have been proposed by Dr. Nayan Sharma (1995):

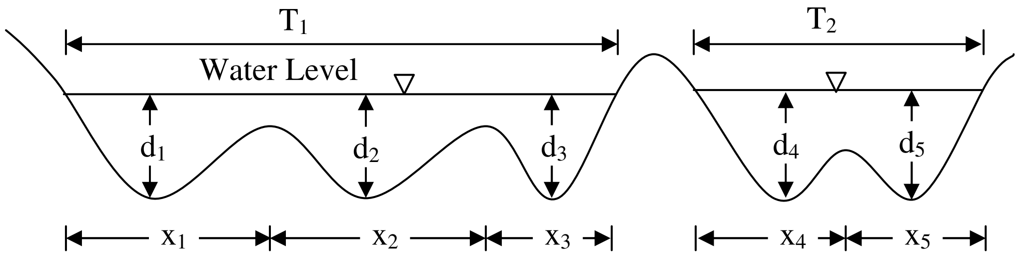
$$\text{Plan Form Index (PFI)} = \frac{\frac{T}{B}\times 100}{N}$$

where, $T = T_1 + T_2$ = Flow top width
B = Overall flow width
N = Number of braided channels

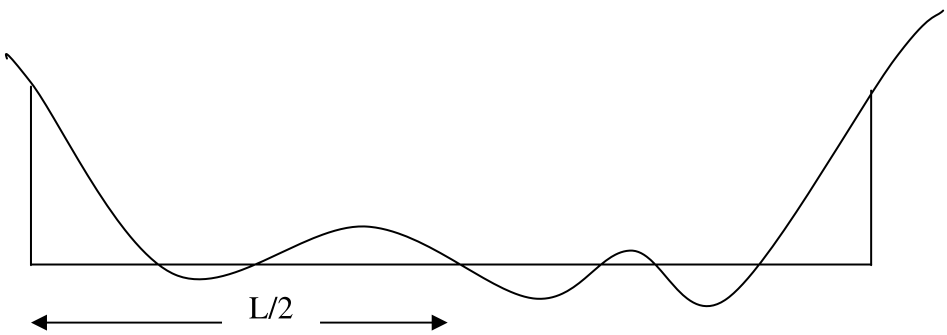


$$\text{Flow Geometry Index (FGI)} = \frac{\Sigma d_i . x_i}{RT}\times N$$

where, d_i and x_i are depth and width of submerged sub-channel
R = Hydraulic mean depth of the stream



Cross Slope = (L/2)/ (Average Bank level-Average bed level)



Plan Form index represents the percentage of actual flow width per braided channel. Obviously, this index reflects the fluvial landform disposition with respect to a given water level and its lower value is indicative of higher degree of braiding.

Flow Geometry Index reflects the underwater sub-channel disposition and the hydraulic efficiency of a braided stream. Its higher value signifies occurrence of higher degree of braiding. Cross slope is basically a form ratio indicator and its higher value indicates higher braiding intensity.

(g) BARS AND SHOALS

Bars and shoals in the river bed may be identified as point bars, middle bars, alternate bars, islands, etc. The changing features of bars/islands associated with meanders/braiding, etc. may be ascertained from the sequential satellite images of different resolutions as per requirement to identify the probable direction of flow pattern/shifting of river courses for consideration in correcting river alignments. Temporal Satellite data may be used to study the river dynamics and area statistics to be derived from the temporal data to find the erosion and deposition characteristics. Unwanted shoals are identified for removal.

(h) BED FORMS

There are several methods of bed form study. However, those by Engelund-Hansen and Garde – Raju could be used.

(i) BED AND ENERGY SLOPES

A comparative study of valley slope, bed slope, water surface and energy slope is made. Excessive energy loss in a reach is associated with significant shoal formations.

Valley slope could be taken from the Survey of India topo sheets. Bed slope observed for reaches may be given. Water surface slope in different reaches, if available, may be given otherwise the same at the G & D sites may be given. Energy slope is drawn with respect to the river-bed taking into account the hydrostatic head (depth) and velocity head, $\frac{V^2}{2g}$.

(j) CHANNEL MIGRATION

Channel migration is believed to be dependent on the variation in discharge from season to season. High variation is usually associated with significant shift in the deepest channel while low variation is associated with comparatively stable channel. There may be some exceptions to this general observation. Relation may however be established between the ratio of maximum discharge to bank full discharge on one hand and lateral channel shifting on the other. In some cases, there is a very good relation between these two parameters. There should be clear distinction between temporary (chute cut-off) and permanent cut-off by using temporal satellite data.

The above morphological parameters are studied to explain the unique characteristics and behaviour of the river and their bearing on various problems. The channel parameters, which need to be corrected / modified to find the solution to the problems, may be identified and the extent, to which such corrections / modifications are required, may be spelt out.

7.0 SUMMARY

A summary of various studies carried out, conclusions arrived at and recommendations for necessary remedial measures should be given at the end of the report. It should also summarize the behaviour of the river and practical usefulness of the morphological studies in future planning and design of remedial measures for flood control/ erosion control.

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ANNEX-I

FORMAT FOR MORPHOLOGICAL REPORTS OF RIVERS

CHAPTER I. INTRODUCTION

i) Introduction
ii) Concept of the study
iii) Objective of the study
iv) Scope of the study
v) Technical approach / Methodology
vi) Data used
vii) Limitations

CHAPTER II. THE RIVER

i) Catchment / Drainage
ii) Topography (this should include flood plains)
iii) Valley slope and bed slope
iv) Flood plain
v) Existing under construction and planned structures
vi) Apparent effects of man-made structures
vii) Land use

CHAPTER III. PHYSIOGRAPHY AND CLIMATE

i) Physiography
ii) Rainfall
iii) Temperature
iv) Humidity
v) Evaporation

CHAPTER IV. SOILS

Soil characteristics and erodability.

CHAPTER V. WATER QUALITY AND UTILIZATION

Water quality, different uses of water including for navigation

CHAPTER VI. GEOLOGY

i) Geo-morphology
ii) Structure and tectonics
iii) Earthquakes/ Seismicity, etc.
iv) Land slides
v) Glaciations

CHAPTER VII. HYDROLOGY

i) Description of lean season and flood season flows with figures of maximum, minimum and dependable flows and bank full discharge.
ii) Water surface slope.
iii) Sediment Transport (during lean season and during floods with figures of coarse, medium and fine sediment).

CHAPTER VIII. PROBLEMS

i) Flood problem: Flood damage, threat to cities etc.
ii) Erosion
iii) Lateral shifting of the river
iv) Problems of city water front, if any
v) Earlier studies

CHAPTER IX. MORPHOLOGICAL CHARACTERISTICS

i) Channel characteristics

   a) Cross section study for variation in area, deepest bed movement (lateral & vertical), description of secondary channels with reference to erosion problem, if any.
   b) Bank full width, mean depth, width depth ratio etc.
   c) Regime status
   d) Lateral slope of river bed.

ii) Aggradation/ degradation of bed
   a) By cross section study
   b) By G-D curve study
   c) By sediment balance study

iii) Relation between sediment transport and different flow parameters including stream power.

iv) Flow characteristics (Relations between different flow parameters with reference to mean velocity and critical velocity).

v) Plan form

   a) Meander or braiding characteristics of the main river.
   b) Changes in Thalweg (This should include meander, geometry, tortuosity, sinuosity, plan form index, flow geometry index, cross slope, etc.)

vi) Bed Forms

   a) Bars and shoals
   b) Analysis of bed forms with reference to flow characteristics

vii) Analysis of bed slope, water surface slope and energy slope with respect to valley slope.

viii) Channel migration.
Shifting of deepest channel with reference to the channel parameters like bank full width, maximum width etc.

CHAPTER X. SUMMARY

ANNEX - II

SPECIFIC INFORMATION TO BE GIVEN IN DIFFFERENT CHAPTERS OF A MORPHOLOGICAL REPORT

CHAPTER I (INTRODUCTION)

- Terms of reference, if any
- Brief introduction with statement of the problem
- Need for morphological studies
- Specific objective and scope of the studies
- Definitions (as per standard glossary of terms)
- Index map (Topo-sheet 1 cm = 25 km)
- Data used
- Limitations of the data and methodology

CHAPTER II (THE RIVER)

- Description of the main river and tributary system (including networks)
- Topography of the catchments, flood plains, deltaic reaches
- Valley slope, bank slopes, bed slope
- Description of flood plain with mention of Khadir limits, significant high and low areas
- Brief description of various river valley projects – existing, under construction and planned with figures of water utilization for different purposes
- Observed ill-effects, if any on the river regime / behaviour during the post project period
- Land use – significant changes from time to time with land use maps.

CHAPTER III (PHYSIOGRAPHY AND CLIMATE)

- Physiography with detailed map of stream, hypsometry curves
- Rainfall pattern, intensities, frequencies, duration etc.
- Temperature (maximum, minimum, mean) in different parts of the basin
- Humidity
- Evaporation (observed)

CHAPTER IV (SOILS)

- Soil types found in different parts of the basin
- Soil characteristics, composition
- Erodability of bank material
- Engineering properties of bank material
- Soil map

CHAPTER V (WATER QUALITY AND UTILIZATION)

- Quality of surface water, ph Value, mineral and metal content, BOD, dissolved oxygen.

- Geo-hydrology with water quality
- Different water uses including for navigation.

CHAPTER VI (GEOLOGY)

- Geomorphology with different geo-morphological maps showing flood plain features like point bars, alternate bars, middle bars, valley plugs, oxbow lakes, palaeo channels etc. with their descriptions and their effect on river behaviour.
- Geology with description of various lithofacies, rock types, erosional characters of rocks, influence of factors like fractures, joints, faults, sheared and shattered zones on river shape and pattern. Structure, tectonics, earthquakes, land slides and their effect on sediment load
- Drainage pattern (Horton's classification), drainage density

CHAPTER VII (HYDROLOGY)

- Temporal and spatial distribution of rainfall, mean monthly and annual isohyets
- Storm movement
- Rainfall intensities for 1,2,3 days
- Isohytal map and maximum intensities observed.
- Description of lean season and flood season flows with figures of maximum, minimum, mean and bank full flows, flood flows of different return periods, brief description of historical floods, 50%, 75%, 80%, 90% dependable lean season flows.
- Water surface slope
- Sediment transport during lean and flood season with figures of coarse, medium and fine sediments.
- Gauge and discharge hydrographs
- Graphs showing typical variation of sediment load with discharge
- Hydrological stations, Inventory of G&D sites with frequency of measurements
- Network analysis of G&D sites.
- Sediment size distribution and concentration of suspended load along vertical direction.
- Bed material size distribution (samples to be collected at 4 to 6 locations at every alternate cross-section from a depth of 30 cm. below the bed).

CHAPTER VIII (PROBLEMS)

- Flood damage, threat to cities/villages, agricultural/ irrigation fields, lines of communication, public utilities etc.
- Bank erosion posing threat to important towns and other populated areas, roads, railways; Apparent causes of the problem.
- Significant lateral shifting of the river posing threat of outflanking of important structures like bridges, barrages etc. besides bank erosion. Possibility of avulsion into another river and the possible consequences thereof etc.
- Significant shifting of the river away from the important towns/ villages/ river bank industries, etc. causing water shortage for drinking, industrial use and irrigation, cooling water for thermal water stations besides degradation of the city environment.

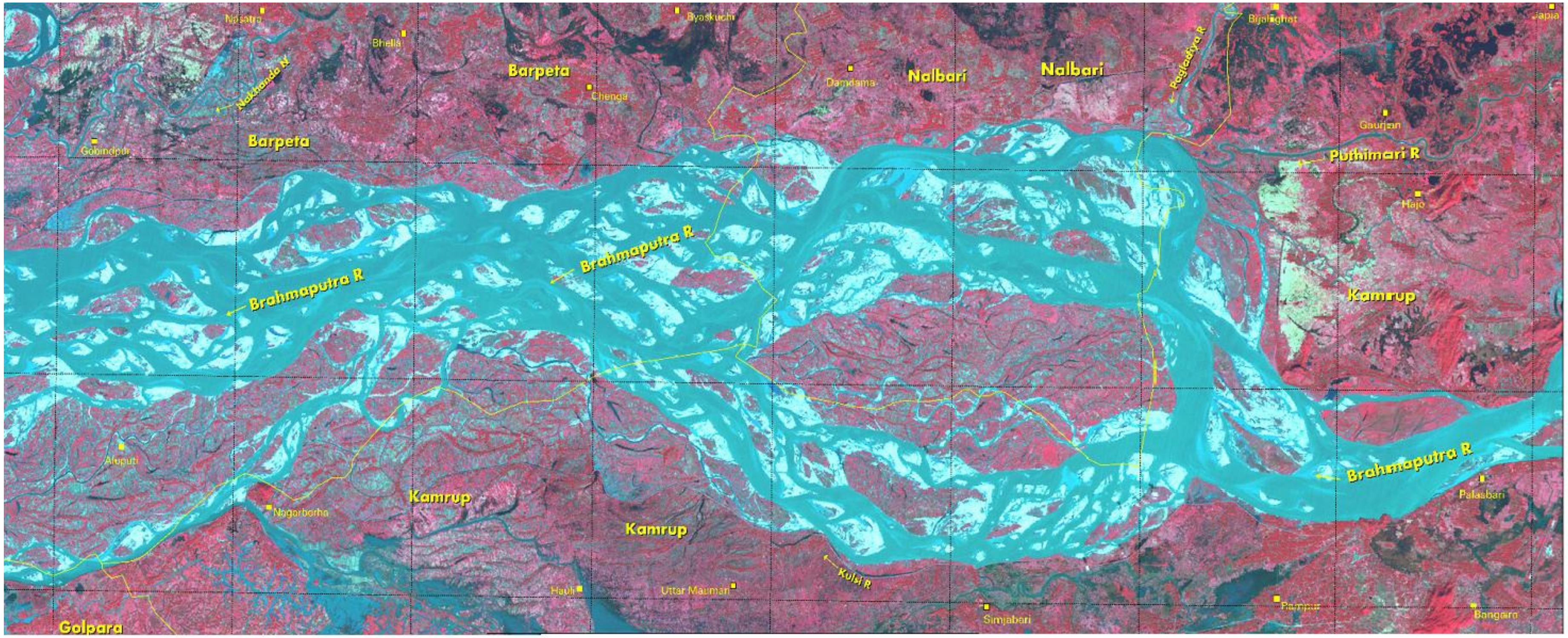
- Earlier studies done by different agencies, remedial measures taken from time to time, performance/ efficiency of the measures and the need for further measures based on morphological studies.

CHAPTER IX (MORPHOLOGICAL CHARACTERISTICS)

- Delineate the courses of rivers and its tributaries with existing major roads, embankments, railway lines, Hydraulic/flood control structures and any other important specific locations with the help of remote sensing data and hydrographic survey data (refer para 6.2)
- Shifting course of river and identify critical locations and rate of shifting
- River flow analysis (refer Para 6.3.1)
- Fluvial geomorphology (refer Para 6.3.2.). It should also contain information in terms of identifying abandoned/ moribandh/ seasonally active spill channels/ meander scrolls/ oxbow lakes etc.
- Channel characteristics (refer Para 6.3.3). These may include plan form changes if any, braiding characteristics and shoal formations, meandering characteristics and sub-meanders, physical constraints like hills and nodal points, bed forms in low, medium and high stages with sonic soundings.
- Regime formulae applicability for width, depth, velocity, slope etc. Changes in Manning's 'n' values.
- Sediment load analysis including rate of sediment transport with comments on transporting capacity
- Identify all major morphological problems both natural and man-made
- Evaluate performance of major flood control structures executed so far from morphological point of view and their effects on river morphology
- Historical information on aggradation and degradation in different reaches
- Lateral migration from historical data
- Khadir limit
- Multi-purpose reservoir and barrages and other structures with their effect on upstream and downstream
- Low water channel characteristics in the context of navigational development
- Catchment area treatment, if any and its likely effect.
- Diagnosis of the problems of land use pattern, general drainage characteristics, flood inundation, flood-prone/ flood-spread area, bank erosion, deposition/ island formation, identification of palaeo channels etc. Scope and limitations of mathematical and physical models including review of available models and their choice.

CHAPTER X: SUMMARY

- Various parameters having a bearing on the river characteristics, behaviour and problems.
- Basic approach to the problems in general and specific recommendations for a lasting solution to the problems.
- Further studies required, if any.
- Additional data required for such studies.



Satellite Image of River Brahmaputra - Down Stream of Guwahati (Assam)