REPORT

OF

THE COMMITTEE ON SILTING OF RIVERS IN INDIA

सत्यमेव जयते

GOVERNMENT OF INDIA
Ministry of Water Resources
New Delhi
December 2002

To

The Secretary
Ministry of Water Resources
Shrama Shakti Bhawan
New Delhi

Sir,

I have pleasure in presenting to you the Report of the Committee on silting of rivers in India, constituted by MOWR vide letter No. 2/11/2000-ER/4285-4311 dated 8.10.2001.

River siltation has been partially studied by many of the past investigators. Silting of river bed is an old phenomenon as alluvium plains have been formed by the silt carried by rivers.

The Committee endeavoured to look into all the possible aspects of silting, keeping in view the terms of reference in the Memorandum as issued by MOWR. We hope that the Recommendations and Suggestions will receive due consideration from the Ministry for taking appropriate measures in this regard.

Finally, I would like to thank the Ministry of Water Resources for the confidence reposed in entrusting this work to us.

Thanking you

Yours sincerely,

(Dr. B.K. Mittal)

REPORT
OF
THE COMMITTEE ON
SILTING OF RIVERS IN INDIA

VOLUME - I

GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
NEW DELHI
DECEMBER 2002

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F.No.2/11/2000-ER | 4285-4311
Government of India
Ministry of Water Resources
(ER Wing)

Block No.11, 8th Floor, CGO Complex,
Lodhi Road, New Delhi – 110003.

Dated: 8.10.2001

OFFICE MEMORANDUM

Sub: Setting up of a Committee to study the problem of silting in rivers.

Large areas of the country are affected by floods every year. Over the years silting of rivers has also assumed serious proportions. This matter also came up for discussion during the meeting of the Standing Committee on Agriculture on the Demands for Grants (2001-2002) as well as Parliamentary Consultative Committee of the Ministry of Water Resources. Accordingly, it has been decided to set up a Committee to study and report on the problem of silting in rivers and related aspects including feasibility of desilting. The composition and terms of reference of the Committee are as under:

2. **Composition**:

1.	Dr. B.K. Mittal, Former Chairman, Central Water Commission	Chairman
2.	Member (RM), CWC, New Delhi	Member
3.	Chairman, Ganga Flood Control Commission, Patna	Member
4.	Chairman, Brahmaputra Board, Guwahati	Member
5.	Secretary (Flood Control), Govt. of Assam, Guwahati	Member
6.	Commissioner & Secretary, Water Resources Deptt., Govt. of Bihar, Patna	Member
7.	Secretary, Irrigation & Waterways Deptt., Govt. of West Bengal, Kolkata	Member
8.	Representative of Dredging Corporation of India Ltd., Vishakhapatnam (Joint General Manager (OPS)	Member
9.	Representative of Central Water & Power Research Station, Khadakwasla, Pune. (Shri M.S. Shitole, Joint Director)	Member

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डायरी सं० DIARY No. 673
दिनांक DATE 11-10-01

10.	Representative of National Remote Sensing Agency, Balanagar, Hyderabad. (Shri A.K. Chakraborti, Group Head (WR)),	Member
11.	Representative from Inland Waterways Authority of India	Member
12.	Representative from Geological Survey of India	Member
13.	Prof. K.S. Sivasami, Centre for the Study of Regional Development, School of Social Sciences, Jawaharlal Nehru University, New Delhi	Member
14.	Sh. B.C. Nayak, Former Engineer-in-Chief, Water Resources Department, Govt. of Orissa. Bhubaneshwar	Member
15.	Chief Engineer (P&D), CWC, New Delhi.	Member-Secretary

3. Terms of Reference

1. To identify cause and extent of siltation in rivers.
2. To suggest measures to minimize siltation.
3. To examine whether desilting is a technically feasible means to minimize magnitude of floods in rivers.
4. To suggest appropriate technology/methods of desilting of rivers if found technically feasible.
5. To find economic viability of desilting of rivers.
6. To propose a realistic operational programme in a time bound manner.
7. Any other related aspect.

4. Expenditure of the Members on TA/DA in connection with the meeting and site visits of the Committee will be borne by the respective Ministry/Department/Organisation. Expenditure in respect of non-official Members will be borne by the Government of India as per rules and regulations of TA/DA in terms of the existing instructions of the Government of India and would be debitable to major head 2711 (Flood Control & Drainage), 01 Flood Control (Sub Major Head), 01, CWC (Plan).

5. The Committee may co-opt any other member if considered necessary commensurate with the terms of reference.

6. The Committee will submit its final report within six months from the date of issue of this Office Memorandum.

7. Hindi version follows.

(M.L. GOYAL)
Commissioner (ER)
Tel.No.4362780

To

1. Dr. B.K. Mittal, Former Chairman, Central Water Commission, 48B, Vijay Mandal Enclave, New Delhi
2. Member (RM), CWC, Sewa Bhavan, R.K. Puram , New Delhi
3. Chairman, Ganga Flood Control Commission, Patna
4. Chairman, Brahmaputra Board, Basistha, Guwahati
5. Secretary (Flood Control), Govt. of Assam, Guwahati.
6. Commissioner & Secretary, Water Resources Deptt., Govt. of Bihar, Patna
7. Secretary, Irrigation & Waterways Deptt., Govt. of West Bengal, Kolkata.
8. Joint General Manager (OPS), Dredging Corporation of India Ltd., Dredge House, Port Area, Vishakhapatnam – 530035.
9. Director, Central Water & Power Research Station Khadakwasla, Pune - 411024.
10. Shri A.K. Chakraborti, Group Head (WR), National Remote Sensing Agency, Balanagar, Hyderabad – 500037.
11. Chairman, Inland Waterways Authority of India, A-13, Sector-1, NOIDA – 201301, Uttar Pradesh.
12. Director General, Geological Survey of India, Calcutta.
13. Prof. K.S. Sivasami, Centre for the Study of Regional Development, School of Social Sciences, Jawaharlal Nehru University, New Delhi – 110067.
14. Shri B.C. Nayak, Formar Engineer-in-Chief, Water Resources Department, Govt. of Orissa, Bhubaneshwar.
15. Chief Engineer (P&D), CWC, Sewa Bhavan, RK Puram, New Delhi – 110066.

Copy also for information to :-

1. PS to Minister (WR), New Delhi.
2. PS to Minister of State (WR), New Delhi.
3. O.S.D. to Secretary (WR), MOWR, Shram Shakti Bhavan, New Delhi.
4. Sr. PPS to Chairman, Central Water Commission, Sewa Bhavan, RK Puram, New Delhi.
5. Member (D&R), CWC, RK Puram, New Delhi.
6. JS & FA (WR), New Delhi.
7. JS(A)/Commissioner (WM)/ (PR)/(PP)/I/CAD, MOWR.

(M.L. GOYAL)
Commissioner (ER)

FOREWORD

Rivers are natural channels to drain water from highlands to lowlands/seas. Over the time, the highlands of an area are worn down. The material thus eroded is utilized further downstream to build banks and lands. As the river flows from high gradient to low gradient, its stream power is lost proportionately, inducing thereby silt deposition en route. The river thus may be likened to conveyance system of transporting silt from highlands to lowlands.

Government of India announced in 1954 its policies relating to Flood Control in the country. Keeping in view the serious nature of flood problems in the country, several ministerial and expert committees have since been constituted to look into the problem and suggest solution in the light of up-to-date knowledge and experience. Government has been orienting its policies/strategies accordingly with the sole objective to alleviate the country of flood menace. The Rashtriya Barh Ayog, the highest body constituted in 1977, thoroughly examined flood problems of the country and submitted its report in 1980 with several recommendations. Flood control schemes – both structural and non-structural have been implemented which have provided flood protection to reasonable degree of probability to about 15 million hectares of the flood prone area. The aforesaid protection in no way guarantees complete removal of flood threat to such areas, for they are always vulnerable to floods of higher magnitudes. Mississippi river in U.S.A., for example, was subjected to flooding in 1993 which caused extensive damage to life and property notwithstanding earlier implementation of several flood control schemes. Elbe river of Europe and Yangze river of China in 2002 have caused damage to life and property. So, if there is flood in a river, it ought to be fully examined and report published to make the people at large aware of its reason.

As of now there is a notion that flood problems are on rise. Rising trend of flooding is generally ascribed to reduced carrying capacity of rivers on account of silt deposition in river beds and encroachment of flood plains by people. No effort, however, has been made to carry out special study in order to find out actual status of silting in a river bed. Standing Committee on Agriculture on Demands for Grants 2000-2001 on the MOWR asked MOWR to study the efficacy of dredging in minimizing the magnitude of floods in rivers. MOWR in pursuance of the above recommendation, constituted the present Committee with suitable terms of reference .

The Committee in its 1st meeting co-opted Dr. K.K.S. Bhatia, as a member to utilize his knowledge and experience on the subject in formulation of the report. In the 2nd meeting, the Committee constituted a Core Group from the existing members to finalise the draft report on the basis of discussions and also on different reports/ literatures, collected from different sources. The Committee held seven meetings at New Delhi and the Core Group had four meetings in New

Delhi and one at N.I.H., Roorkee wherein the members deliberated upon the terms of reference in order to finalise the report.

The Committee has referred to voluminous literature/articles collected, in order to determine the trend of siltation in different national and international rivers. There is no study/article available which conclusively establishes the fact that there is rise of flood menace in the country, due to siltation in rivers. There are, of course, certain locations where silting is reported to have occurred such as tidal rivers, confluence points etc. In fact, in India excepting a few rivers, continuous embankments along river reaches are not existing. Still the Committee examined different possible solutions which could be applied to reduce aggradation in river.

The cooperation extended by the Members of the Committee in finalizing the report is gratefully acknowledged. Members were all very busy in their normal occupations, yet they managed to attend most of the meetings and contributed substantially in finalisation of the Report. I express my deep appreciation for their work.

The Member Secretary of the Committee, Shri S.K. Sengupta, Chief Engineer (P&D), CWC had the responsibility of organizing the meetings, liason with Ministry of Water Resources and State Governments, preparation of agenda and minutes of the meetings, collection of reports and relevant documents from different organizations/ departments. I would like to record my appreciation for the most efficient and excellent way Shri Sengupta performed his tasks. Thanks are also due to Shri G.Thakur, Director (Morphology Dte) and officers and staff of Morphology Directorate of Central Water Commission who have worked untiringly to bring out this report.

I have the pleasure to submit the report on "Silting of Rivers in India"

Sd/-

Date : **Dr. B.K.Mittal**

EXECUTIVE SUMMARY

1.0 INTRODUCTION

River valleys and deltas are endowed with favourable combination of lands, water and heat required for population settlement. This is exemplified by the fact that all ancient civilizations namely Harappan Civilisation in India, Mesopotamia in Modern Iraq, Egyptian in Egypt and Chinese civilization in China flourished in the river valleys; so they are sometimes called the River Valley Civilizations. The Harappan civilization flourished in the Indus Valley. The Mesopotamian civilization flourished in the Tigris-Euphrates valley, while the Egyptian civilization and the Chinese civilization flourished on river banks of Nile and Hwang-Ho respectively. Modern cities are generally situated in river basins. Urbanization has a bearing on the flood problem as growth of urban population coupled with high development activities in the urban areas increases the flood potential by reducing agricultural land area replacing the depressions in the flood plains by paved areas.

Apart from embankment, there are other methods which have been adopted since ancient times. For instance, the Minneriya Tank in Sri Lanka was constructed in the Third Century B.C. Flood has been bedeviling man since early times. J.Chia, the highest authority in charge of the Yellow river prepared a flood plan in the 8th century B.C., wherein he recommended among other things, vacating densely populated area along river banks and returning back the vacated land to the rivers. In Yellow river, a system of "*loute*" (near dykes) for confining the flow to scour the river bed and another system of "*Yaoti*" (far dykes) to provide protection against floods were followed in the 16th century.

Yellow and Kosi rivers have unstable, cone-shaped courses and convex valley. Both these courses have shifting tendencies. River Kosi has shifted westward about 112 kms during last 200 years. The river Ganga, on the other hand, has a stable course in its depressed valley and flows along the deepest thalweg. The flooding is, therefore, contained in the concave bowl in the Ganga basin . (*Flood Control in the World, Volume-I, 1976, ICID*).

2.0 CONSTITUTION OF THE COMMITTEE

This is the first committee constituted by Ministry of Water Resources, to study and report on the problem of silting in Indian rivers and related aspects including feasibility of desilting. The Committee, therefore, had to start from scratch. Several articles, reports, books were referred ,out of which a few ones contained river silting. The Committee was interested at first to familiarize itself with actual status of silting in Indian rivers. The Committee, did not pursue any specific study except the one carried out by CWC on its sites to determine the trend of aggradation/degradation in rivers like Ganga, Brahmaputra, Godavari, Krishna, etc. The Committee delved into the aspect vis a vis silting in flood prone rivers in India. There is ample material included in the report which has depicted the staus of silting in Indian rivers.

3.0 TERMS OF REFERENCE

While constituting the Committee MOWR has included 7 Terms of Reference on which Committee had to restrict its functioning. The terms of reference are as noted;

(a) To identify cause and Extent of Siltation in rivers :

(b) To suggest measures to minimize siltation

(c) To examine whether desilting is a technically feasible means to minimize magnitude of floods in rivers.

(d) To suggest appropriate technology/methods of desilting of rivers if found technically feasible.

(e) To find economic viability of desilting of rivers.

(f) To propose a realistic operational programme in a time bound manner.

(g) Any other related aspect.

4.0 GLOBAL SCENARIO

In India effects of floods may be experienced in the form of flooding, drainage congestion and bank erosion. Rashtriya Barh Ayog has divided India into 4 groups:

(i) Brahmaputra region

(ii) Ganga region

(iii) North – West region

(iv) Central India and Deccan region

In India , floods are experienced as channels are not capable of draining off the copious quantities of runoff, resulting from heavy precipitation. Aggradation of river may also lead to flooding like in Brahmaputra river following the severe earthquake of 1950. Flooding is also caused when natural drainage system is disturbed due to rail and road crossings or when there are encroachment in the flood plain.

According to the morphological report on Brahmaputra (1993), there is no appreciable aggradation of the Brahmaputra river. Desilting of river Brahmaputra with the help of Dredging operation was not found efficacious. (Ref Annex- Vol.II)

Tamil Nadu government has completed a project of desilting and removal of ipomea in rivers, drains and channel in the Cauvery delta at a cost of Rs. 111.97 crores. Another project in progress is "Rehabilitation of Chennai Waterways" by removing silt and sludge deposited in various waterways of Chennai at a cost of Rs. 300 crores.

The Tilaya, Maithon, Konar and Panchet Hill reservoirs with a total capacity of 0.1845 m ha.m, can moderate floods to the extent of 2.5 lakh causes in Damodar river. DVC has planned for soil conservation measures in the catchment areas of theses reservoirs.

National Institute of Hydrology reviewed the problem of erosion, sedimentation and flooding in river Kosi. The IIT, Delhi conducted a project to determine the rise and fall of the river bed elevation prior to and after the construction of Kosi project in the year 1963. Based on the analysis of 98 cross sections for the year 1955 to 1974, it was found that after the construction of the barrage, three reaches showed a tendency to change from degrading to aggrading and two reaches showed a tendency of reduced rate of degradation.

The Technical Committee appointed by Govt. of Bihar concluded as below:

i) Siltation to the extent of 1.04 m to 1.44 m is found to have occurred in the bed upstream of the barrage.
ii) Cubarature study and gauge observations should be undertaken at selected locations to identify the changes in the river bed levels.
iii) Measures like periodical flushing and running of silt-excluder should be adopted to control sediment entry into Kosi canals.

China experiences frequent flooding and as such it has a long history of managing floods. About one tenth of China's territory is occupied by two thirds of the population. This territory is below the flood level of major rivers – Yellow and Yangtze. In 1998, 35 million hectares of land was affected by flood, causing 3500 deaths besides damaging 21 million dwelling units. The cost of the damage was estimated equal to 32 million US dollars. (WMO 1999)

The Chinese Govt. is making all out efforts to combat the flood menace. In Yellow river, for example, the approach is three fold namely u/s reservoir in the upper reach ; detention and flood storage in the middle reach and widening , deepening of river course in the lower reach. In the lower reach of Yellow river non-structural measures are also implemented to minimize the adverse impacts of floods.

The Bangladesh Government has taken up a project of dredging 530 km. of river ways. Under UNDP project the department of sedimentation of China Institute of Water Resources and Hydro power research is doing a feasibility study of desilting to medium and minor rivers in Bangladesh

The United States of America experienced the worst flood in the year 1993. In a span of about four months flood in the Mississipi river basin killed 50 people, left another 70,000 homeless and caused more than 50 billion of property damage. World Wildlife Fund's panel subsequently reviewed the flood and recommended locally driven watershed focused approaches to flood damage reduction .

The Delaware river federal supporting channel dredging project, costing $ 311 million, which was taken up in 1999, was suspended in 2002 as doubts were expressed on the cost-benefit of the project.(Internet)

British Columbia disapproves dyke construction as a flood control measure and adopts the planning and regulation of development in flood plan as a strategy for reducing overall damage from flooding.(Internet)

In Birmingham the river Tame enlarged in 1930 as a part of flood protection project had reverted to its original size by 1959.(Ward, R.C 1978)

5.0 PROCESS OF SEDIMENTATION AND SILTATION

Due to various factors silt erosion in the catchment areas of Himalayan rivers is more in comparison to central and south Indian rivers. The sediment transport in a river channel is a complex phenomenon because of which still empirical methods are employed to assess the silt load in a river. Sediment properties such as size, shape, density, specific gravity, fall velocity and porosity are required for understanding the subject of silt plan.

Siltation process is subject to several factors including physiography, geology, meteorology, hydrology and flow characteristics of the particular river. In general there is erosion in the upper reach and deposition in the lower reach because of which morphological changes are manifest in middle and lower reaches of a river. Silt deposition is accentuated in lower reaches of alluvial and coastal rivers.

Embankment is one of the several structural measures of flood management which has been used in India in almost all flood prone basins.

6.0 GEOLOGICAL FACTORS IN SILTATION :

6.1 Geology

India has been divided both geologically and geographically into three distinct units.

- Peninsular Region.
- Extra Peninsular Region.
- Indo-Gangetic/Brahmaputra Alluvial Plains

6.1.1 Peninsular shield

Physiographically the peninsula is an ancient plateau having rivers of shallow and broad valleys. Major mountain ranges of peninsular India are the Western Ghats, Eastern Ghats, Vindhyas, Satpuras, the Aravallis and those forming the Meghalaya plateau and Mikir Hills. The important rivers flowing in this region include Godavari, Krishna, Cauvery, Narmada, etc.

6.1.2 The Extra-Peninsula Region

These are surrounding India on the north and northwest and northeast. The tectonic ranges resulted from collision of Indian Plate with northern Eurasian Plate. Of these, Himalayas and Burmese arc are of importance in the context of Indian rivers. Himalayas, based on physiographical, geomorphological and tectonics have been divided into Inner Himalayas or Central Himalayas,Lesser Himalayas and Foot Hills or Outer Himalayas or Frontal Fold belt.

6.1.3 Indo-Gangetic/Brahmaputra Plains

Indo-Gangetic planes are great planes through which several rivers, like Ganga, Brahmaputra, Kosi, Gengtok, Ghagra, Tista, etc. flow. This is the most densely populated region and severely flood-prone. The rivers in this region are characterized by flooding, shifting tendency, etc. These rivers originate in the Himalayas and their catchment areas, like in hilly terrain. These rivers have changed their courses frequently in the past. Compared to this, the changes by peninsular rivers are not so marked.

6.2 Structure Tectonics And Seismicity

In case of structure, tectonics and seismicity also India can be divided into two domains, i.e., Peninsular domain and Extra-Peninsular domain that includes northeastern region. The extra-Peninsular that includes Himalayas is plate margin region as it lies on boundaries of India Plate as seismicity is interplate seismicity, whereas Peninsular domain is termed as intedior region or intra plate domain and seismicity is of intraplate nature.

6.3 Land Slides, flooding and sedimentation

Landslides are common in hilly areas which cause enormous loss to land and property. Globally landslides cause approximately 1000 deaths every year with property damage of about US 4 billion dollars besides contributing huge silt load to river. It is a major natural hazard with which a considerable area of the country has to contend with. The slope unstability in Himalayas can be related with geology, geo-morphology, seismo-tectonic set-up and geo-dynamics. Landslides, climatic factors, land use pattern are important in inducing slope instability, such as fragile nature of rocks, active nature of tectonics in plate margins along with climatic factors.

Heavy rainfall has been the main cause of floods in river basins in India. A study shows Ganga river is in aggradation stage at Allahabad, Shahzadpur and Mirjapur on average. Similarly, Gomti was also aggradational at Sultanpur, but degradational at Zaunpur. However, at macro level, out of ten cross sections at Allahabad, seven indicated the Ganga to be in aggradation whereas at three locations, it was degradation.

In case of Brahmaputra as stated by Goswami (1998), the basin represents a unique physiographic setting vis-à-vis eastern Himalayas, a powerful monsoon fed regime under wet humid conditions, a fragile geological base and active siesmicity. The gradient is as flat as 0.1 m/km. The Brahmaputra is underlain for most part by very young and sedimentary formations and hence carries mainly fine sand and silt with very little clay. The river is ranked fourth among the largest rivers of world with an average annual discharge of 19830 m3 s at mouth. Brahmputra is one of the major sediment transporting large rivers of the world and the sediment transported per unit drainage area 1128 m tons/km /year at Bahadurabad in Bangladesh and same is only 804 m tons/km /year at Pandu near Guwahati.

The lateral expansion of river channel and decline in their slope in the mountain foreland causes the flattening and reduction in the energy of flood waves as reflected in extensive deposition over the alluvial fans.

RBA states that the channel improvement method should be tried with caution after technical and economic viability and ensuring that the improvement to be brought about are of a sustained nature. There is a need for collection of dependable data on the performance of such operations.

7.0 REMEDIAL MEASURES VIS-À-VIS SILTATION OF RIVERS IN INDIA

The silt load and erosion/deposition depend on catchment characteristics, climatic conditions and hydraulic characteristics of flow. In any river system the siltation process is dependent on natural and man made factors. For example deforestation, especially in the upper catchment leads to increased rate of soil erosion and consequent silt load.

Watershed management may remedy the siltuation as it is a potent technique to hold / arrest silt in a catchment which otherwise enters into the stream and incrases the silt load downstream. Hydraulic structures too are effective in trapping silt as they function as control structure.

Dredging operation is a mechanical method which may be carried out in tandom with watershed management and other flood control schemes. Dredging may be appropriate for tributaries as their silt load add to the overall silt load of the main river.

While carrying out dredging operation, the environmental aspects should be taken care of. The dredging operation disturb the upper layers of the river bed which house dwelling places of aquatic plants and animals. The turbidity caused by the dredging operation reduces photosynthesis effect of the sunlight, thereby depriving food supply to the plant and animal in the river bed. Dredging operation does cause water pollution because of huge fuel consumption. So, environmental impact assessment in respect of dredging operation should be done in order to ward off adverse environmental effect.

In India there is no Act as yet directly pertaining to dredging. Dredging operation however has to be carried out in conformity with various laws of the land. Dredging has been recommended in the Indian rivers in exceptional circumstances for flood mitigation and navigation.

8.0 SPECIAL PROBLEMS OF SILTATION/EROSION

8.1 Krishna river :

There are two reservoirs in close proximity in Krishna river namely Srisailam and Nagarjunasagar reservoirs, one downstream of the other. Hydropower is generated from the release of Srisailam reservoir which receives water from Nagarjunasagar reservoir also by reverse pumping. With the help of satellite data, the presence of 4 major stream outfall deposits in Krishna river reach of 13.5 km. from the Srisailam Dam which were the principal contributing factor of discontinuity in water pool which takes place when the water level of Nagarjunasagar reservoir is low, was identified.

Selective dredging has been recommended by NRSA, Hyderabad to ensure continuity in flow. Dredging after all, is a short term measure. Watershed management is a long term measure which in fact stems silt generation in a catchment, reducing silt load consequently.

In Krishna river, Gabion type check dam has been recommended.Gabion type check dams are permeable to rain water flow and at the same time these hold back the rain wash-out materials.

8.2 Bank Erosion in Majuli island in Brahmaputra

Majuli island having an area of approx. 900 sq.km. is situated in the river bed of river Brahmaputra. The river Subansiri from north meets the Brhmaputra near the Majuli island.

The Majuli island is facing erosion problem since last few decades as such its area is shrinking gradually. It is an important historical place needing preservation for the posterity. The rate of erosion depends on various factors such as severity of attack, angle of incidence, river water turbulence, grainometric and other physio-chemical characteristics of the bank soils and their statistification.

According to one estimate, 35 villages in Majuli island have been eroded by the two rivers i.e. Brahmaputra and Subansiri. Since 1954, the erosion has increased and still continues.

Remote sensing technique is useful to assess :-

i) The land affected
ii) Depicts river configuration
iii) Delineates bank erosion for fixing priority in respect of anti erosion schemes.

The study group constituted by Government of India in 1964 has concluded that the northern bank of Brahmaputra has undergone erosion for a length of 230 km between Kobo (d/s of Pasighat) and Dubri.

In the latest study of 1996 commissioned by Brahmaputra Board, NRSA has estimated that total 50.27 sq.km. of land has been lost due to erosion in the river Brahmaputra during 1969-1994. The erosion caused by Subansiri is comparatively less.

NRSA, based on satellite data and ground verification has categorized three types of bank erosion in Brahmaputra as noted below :-

i) Major erosion affecting large area
ii) Moderate erosion affecting certain areas along bank line

iii) Minimum erosion at isolated sites

Several anti erosion measures are adopted in the field, like construction of embankment, channel improvement, diversion of channel, partial diversion of flow, etc.

NRSA has recommended for model study before finalizing anti erosion schemes.

8.3 Bank erosion of river Brahmaputra

River Brahmaputra is characterized by its changing behaviour, especially in Assam. During monsoon season, the thalweg changes, accompanied by erosion/deposition at several places.

Remote sensing technique is useful to find out river configuration and active river channel flow at different times. NRSA has carried out a study of river configuration of river Brahmaputra from Taliyagaon to Rajkot Mehang hills using multi satellite digital data of post flood period of 1990,1994 and 1998, the conclusion of which are noted below :-

i) During the period 1990-94, it is observed that erosion has taken place at Garubandha, Baralimarigaon, Bartal Dalaigaon, Taliyagaon, Singri, Shyampuri and Cherangchopa. Maximum erosion on the left bank is about 1.8 kms at Garubanda during this period.

ii) During the period 1994-98, it is observed that erosion has taken place at Garubandha, Bhakajari, Baralimarigaon, Barkur, Taliyagaon, Singri, Shyampuri and Cherangchopa. Maximum erosion on the left bank is about 2.1 km at Baralimarigaon.

iii) The maximum extent of erosion is observed near Garubandha on the left bank, which is about 2.16 km and near Erabari on the right bank which is about 2.12 km.

Remote Sensing technique is also useful in determining braiding/meandering tendency of the river. It also helps in identifying active channel at any particular time.

8.4 Flood/drainage congestion in Yamuna river near Delhi

There was an unprecedented flood in river Yamuna in 1978 which affected half a million population and submerged about 1,813 sq.km. of agricultural land. River Yamuna has been protected by embankment from either side in Delhi creating flooding problem in the vicinity of national capital.

9.0 RECOMMENDATIONS AND SUGGESTIONS

9.1 River siltation has apparently been not studied in totality by any of the past investigations. Silting of river bed is not a new phenomenon as alluvium plains have been formed by silt carried by rivers. The river while flowing from upland to lowland carries along with it silt, a part of which is dropped by the river en route to its outfall.

The Geological Society of India (No. 41, 1998) has brought out a comprehensive report on Floods in India. Prof. Thomas Hofer, Deptt. Of Geology has studied floods in India for the last 40 years (1953 to 1993) and has provided a preliminary indicator of siltation of rivers and this shows that there is no increasing trend of magnitude or frequency.

India has been pursuing flood control schemes since 1954. The flood damage has been simultaneously rising notwithstanding considerable expenditure incurred on these schemes in the past few decades. This is more due to encroachment of flood plains. Embankments are effective for a low flood but for high floods they may rather be a hindrance as it cannot afford protection in case of high floods, though it fosters the impression of security. However, embankments serve an important function in flood management.

Flooding in Ganga, Brahmaputra, Meghna System is not new. Shifting of the course of these rivers in certain reaches is also a common phenomenon. For example, the Brahmaputra, which before 1789 was a tributary of Meghna, joined Ganga following severe earthquake which occurred in 1789.

The Yellow river of China in its lower reaches has been severely subjected to silting so much so that its river bed is about 3-3.5 m above the general ground level. In case of Yellow river, Chinese experts have taken resort to raising of embankment height in order to offset against the consequent rise in river stage.

In pursuance of harnessing water resources potential several schemes have been implemented in rivers following which morphological changes have taken place. Flood control schemes especially embankments are said to affect morphological behaviour of a river as they confine the river flow from spreading on either side. Embankments have been constructed on flood prone rivers in almost all countries where flooding is experienced. In India several thousand kms. of embankment are existing along flood prone rivers especially in Ganga and Brahmaputra river systems. Therefore, theoretically speaking these rivers are supposed to undergo morphological changes.

The Committee ,therefore, endeavoured to find out the published literature related to such studies which could corroborate the above line of thinking. The Committee did not pursue any special study in order to determine the true status of silting in Indian rivers. This limitation notwithstanding, the Committee collected voluminous literature on silting of rivers. Several State Governments viz. Orissa, West Bengal and Assam submitted materials on silting and its effects in response to the request of the Committee. The studies carried out by WATER AND POWER CONSULTANCY SERVICES (INDIA) LIMITED (A Government of India Undertaking) for North Eastern Council on "Morphological studies of River Brahmaputra" in 1993 thoroughly looked into the morphological behaviour of river Brahmaputra including aggradation.

It is a known fact that tidal rivers are generally prone to silting thereby causing drainage congestion and flooding. Likewise, the confluence of a tributary to the main channel is generally subjected to silting. Right from the first meeting dredging has been an important topic of discussion. Its efficacy for flood management has been in doubt in view of the several practical problems such as cost involved, disposal of dredged material and sustainability of the solution suggested. To quote two typical examples, West Bengal Government could not carry out dredging operation in Ichamati river due to non-availability of suitable land for disposal of the dredged material. Assam Govt. in 1978 carried out dredging operation in Brahmaputra which was abandoned subsequently as it had no positive impact. Dredging has, therefore, been found to be not so effective in general. However, the Committee has suggested *selective dredging* depending on local conditions to improve the hydraulic characteristics of the river.

9.2 Committee meetings

The Committee held 7 meetings, all in New Delhi where experts from Central Water Commission, Brahmaputra Board, GFCC, GSI, NRSA, NIH, JNU, IWAI, CWPRS, DCI, Government of Assam, Bihar, West Bengal and Orissa met to deliberate upon the subject. Two background notes for the first and second meetings were circulated by Central Water Commission wherein some of the available information was compiled so as to facilitate members to hold discussions.

9.3 Problem of Silting

Aggradation is a process in which the bed of a river rises as a consequence of deposition of sediment. Continuous aggradation in a river may lead to reduction of carrying capacity and hence overtopping.

Due to aggradation in Irlamaz river in Turkey, the city Salihi was flooded and rail road damaged. Government of Turkey took precautions to stop aggradation. Further details, however, could be not available in this regard. The Yellow river of China whose bed level is about 3-3.5 meters above the general ground level, is a case of great interest.

In respect of our own country, several tidal rivers in Orissa have been reported to be subjected to silting causing drainage congestion and flooding. The river Brahmaputra at Dibrugarh had undergone morphological changes following an earthquake of 1950. The bed level had risen in considerable reaches resulting in the raise of minimum water level substantially. The morphological report of Brahmaputra Board has mentioned aggradation in the upper reach of Brahmaputra.

In case the silting is taking place in a river bed continuously, either the bed level is to be lowered or embankment raised to make good the loss of carrying capacity. There can hardly be any solution which can be universally adopted. The solution in fact has to be location specific.

9.4 Status of Silting

The Committee thoroughly looked into this aspect with the help of available literature collected by CWC. In order to work out quantitative figure of aggradation/degradation, a few sites on Ganga, Brahmaputra, Godavari, Krishna,etc, were selected where cross-sectional areas of last 5-10 years were superimposed. The result has been appended in order to buttress the view that aggradation, contrary to the general impression, is not pronounced and alarming. This can be so in respect of many other Indian rivers also.

The Brahmaputra Board carried out detailed analysis of sixty five cross sections taken along the river Brahmaputra which has been reflected in the Master Plan prepared by Brahmaputra Board. It was also concluded in the report of NEC prepared by WAPCOS on Morphological studies of river Brahmaputra, 1993 that aggradation is limited to very short length, that too for a short period (Para 8.2.5 of Morphological studies of River Brahmaputra, 1993) Over a long period of 32 years from 1957 to 1989, the study indicates that an overall degradation in almost the whole length of the river has taken place.

As per the literature available from Water Resources Deparments, Orissa and West Bengal, coastal rivers of Orissa and West Bengal have been subjected to aggradation causing drainage congestion and flooding. Kosi and other rivers of Bihar have also been reported to induce silting in river beds. This, however, has not been substantiated by specific data. Carrying capacity of a river should, therefore, be monitored on regular basis to obtain a correct knowledge regarding aggradation/degradation. Obviously, relevant data are required to be collected in future; this could then be analysed to understand the nature of silting process.

9.5 Identification of cause and extent of Siltation in Rivers.

Silt flow is an inherent part of river flow. The flow from steep gradient to low gradient is always accompanied by erosion in upper reach and deposition in the lower reach. Himalayan rivers originate from geologically unstable regions of

Himalayas which are seismically active as well. Faulty land use practices/deforestation have exacerbated the erosion problem in hilly regions of Himalayas. Peninsular rivers are not so much prone to siltation. Coastal rivers have intrinsic nature of siltation mainly due to natural and tidal causes. Though there is heavy sediment load in rivers, the natural process of *'self scouring'* ensures that there is no substantial aggradation, in totality.

9.6 Measures for minimizing Siltation.

As siltation is a part of river system, earlier Committees/experts have stressed upon the necessity of reducing silt load in rivers particularly those which are flood prone. Morphological behaviour of a river is greatly influenced by silt load that a river carries.

The method of minimizing siltation may be of two fold –one that is required in the catchment and the other in the river itself. The method to be adopted in the former viz the catchment may include afforestation, right practice of land use, catchment area treatment, and others. The method in respect of later viz 'the river itself' may include construction of suitable hydraulic structures that may trap silt. Embankment along the aggrading river should be constructed, only after proper studies are made on its behaviour especially due to sedimentation load & resultant morphological changes.

9.7 Efficacy of Desilting of river bed vis-à-vis Flood problem

The Committee considered this aspect and found desilting in general is not feasible technically, due to several reasons like non-sustainability, non-availability of vast land required for the disposal of dredged material, etc. The desilting by dredging operation was specifically discussed by committee. It arrived at the conclusion that dredging in general should not be resorted particularly in major rivers. There are, of course, some locations such as tidal rivers, confluence points and the likes which can be tackled by desilting after thorough examination.

Desilting of rivers can marginally minimize the magnitude of floods and be effective only for a short period. This cannot be viewed in isolation of other approaches to manage floods. In view of the limited scope, desilting is not recommended on a large scale. However, desilting can be done in vulnerable reaches for some specific purpose which are to be identified by the state governments and local people, and the experience should be evaluated for further applicability. For navigation purpose the river reaches in the waterway path need to be dredged every year, to have minimum depth of water. However, this will have insignificant effect on flood control.

9.8 Appropriate Technology / Method of Desilting of rivers , if found Technically feasible.

The Committee is of the opinion that in cases where siltation has taken on one bank and erosion on the other bank of the river, silt can be removed from the deposited area and dumped on the suitable area with proper investigation. This can be by simple dozing. Experiments may be conducted to assess the effectiveness of artificial flood waves in flushing the silt downstream especially around the confluence of large tributaries with main river.

All major rivers of North India straddle the international border between India and Nepal /Bhutan /Myanmar. The catchment area treatment will necessitate an understanding with these countries so as to undertake such schemes and implement. For example, understanding with Royal Govt. of Nepal is required to implement schemes which may reduce silt load in rivers of North Bihar in general and Kosi, in particular.

The Department of Sedimentation, Chinese Institute of Water Resources and Hydropower Research is understood to have taken up feasibility study of desilting of 20 medium and minor rivers in Bangladesh(funded by UNDP). It will be worthwhile if Ministry of Water Resources, Government of India can establish rapport with the Department of Sedimentation, China for exchange of information in this project.

The feasibility of conducting similar studies upstream of Farakka in order to manage the silt problem may be explored.

9.9 Determination of Economic viability of Desilting in rivers

The Committee is of the opinion that desilting of rivers for flood control is not an economically viable solution.

9.10 To propose a Realistic Operational Programme in a time bound manner.

The Committee is of the view that a specific scientific study needs to be taken up by NEHARI under Brahmaputra Board, Irrigation Research Institute, Roorkee, River Research Institute, Calcutta, CWPRS, Pune and other similar organisation in the country to establish the cause of aggradation/degradation in any affected river and to suggest different remedial measures to minimize/remove the siltation problem. Once these measures are implemented and proved successful, the same can be considered for other affected areas with similar conditions.

CHAPTER - I

INTRODUCTION

Water is one of the five elements known as *panchamahabhut* in ancient literature. Water is absolutely essential, rather, indispensable for sustainability of life. Life originated in water first. With passage of time, interference in the nature has been increasing. Because of adverse impact of the development, sustainable development has now become a buzz-word. In actual practice, we have been attempting to make nature adapt according to our own necessity and convenience. As a result, several complications have manifested in different forms; flood problem is one of them. Flood which was boon to the people in the past, has turned out a vice, because of shear mismanagement.

The Committee was constituted by the Ministry of Water Resources, Government of India to study the behaviour of the silting of rivers and suggest appropriate measures to check the morphological changes. The Committee has referred to many articles, papers, reports, books to collect the relevant information to the extent possible. The Committee was interested at first to familiarize itself with actual status of silting in Indian rivers. The Committee, did not pursue any specific study except the one carried out by CWC on its sites to determine the trend of aggradation/degradation in rivers like Ganga, Brahmaputra, Godavari, Krishna, etc. The status of the silting has been duly addressed by the Committee. The Committee adhered to the terms of reference as mentioned in MOWR notification.

1.0 CONSTITUTION OF THE COMMITTEE

The Govt. of India and State Governments have been pursuing flood control schemes since 1954 when policy documents on floods in the country were presented to the Parliament. Huge expenditure has been incurred by the country on flood management with simultaneous increase in flood damage. Some new areas which were hitherto immune to flood, have recently been subjected to flooding. One of the reasons, attributed in this regard is cited the reduced carrying capacity of flood prone rivers

This matter came up for discussion during the meeting of the Standing Committee on Agriculture on the Demands for Grants (2001-2002) as well as Parliamentary Consultative Committee of the Ministry of Water Resources. During the meeting, Ministry of Water Resources was asked to look into silting of rivers in India and take needful action in this regard. In pursuance of the above fact, MOWR constituted the committee with members and Terms of Reference as noted below.

1.1 Composition of the Committee

1.	Dr. B.K. Mittal, Former Chairman, Central Water Commission New Delhi	-	Chairman
2.	Member (RM), Central Water Commission, New Delhi	-	Member
3.	Chairman, Ganga Flood Control Commission, Patna	-	Member
4.	Chairman, Brahmaputra Board, Guwahati	-	Member
5.	Secretary (Flood Control), Govt. of Assam, Guwahati	-	Member
6.	Commissioner & Secretary, Water Resources Deptt., Govt. of Bihar, Patna	-	Member
7.	Secretary, Irrigation & Waterways Deptt., Govt. of West Bengal, Kolkata	-	Member
8.	Representative of Dredging Corporation of India Ltd., Vishakhapatnam (Joint General Manager, OPS)	-	Member
9.	Representative of Central Water & Power Research Station, Khadakwasla, Pune. (Shri M.S.Shitole, Joint Director)	-	Member
10.	Representative of National Remote Sensing Agency, Balanagar, Hyderabad. (Shri A.K.Chakraborti, Group Head(WR))	-	Member
11.	Representative of Inland Waterways Authority of India	-	Member
12.	Representative from Geological Survey of India	-	Member

13. Prof. K.S. Sivasami, - Member
Centre for the Study of Regional Development,
School of Social Sciences,
Jawaharlal Nehru University, New Delhi

14. Sh. B.C. Nayak, Former Engineer-in-Chief, - Member
Water Resources Department,
Govt. of Orissa. Bhubaneshwar

15. Chief Engineer (P&D), - Member Secretary
Central Water Commission,
New Delhi.

At the First Meeting of the Committee, it was decided to co-opt Dr. K.K.S. Bhatia, Sc. F, National Institute of Hydrology, Roorkee and Prof. K.G. Rangaraju, Deputy Director, Indian Institute of Technology, Roorkee as members of the Committee.

1.2 Terms of Reference

1. To identify cause and extent of siltation in rivers.
2. To suggest measures to minimize siltation.
3. To examine whether desilting is a technically feasible means to minimize magnitude of floods in rivers.
4. To suggest appropriate technology/methods of desilting of rivers if found technically feasible.
5. To find economic viability of desilting of rivers.
6. To propose a realistic operational programme in a time bound manner.
7. Any other related aspect.

1.3 Core Group

In the second meeting, the outline of the draft report was decided by the Committee. A Core Group was constituted to make use of all the data and information that were received from members of the Committee. The Core Group functioned as a working group of the Committee and concentrated on the preparation of the report. The Core Group consisted of following officials/ members:

1. Shri B.C. Nayak,
   Former Engineer-in-Chief
   Irrigation Department, Orissa

2. Professor K.S. Sivasami,
   Jawahar Lal Nehru University,
   New Delhi

3. Dr. K.K.S. Bhatia, Sc. F,
   National Institute of Hydrology,
   Roorkee

4. Shri Suresh Chopra, Director,
   Geological Survey of India,
   Faridabad

5. Shri Gorakh Thakur,
   Director (Morphology Dte.),
   Central Water Commission, New Delhi

1.4 Meetings of the Committee and the Core Group

The Committee held 7 meetings all in New Delhi, having extensive and thorough discussion on all Terms of Reference. Several issues such as flood problem, carrying capacity of rivers, efficacy of dredging operation vis-à-vis flood control, practicability of possible solutions were discussed. Members contributed material in their official as well as individual capacity. The Core Group which was constituted in the second meeting made use of the material supplied by members.

The Core Group also held 5 meetings. One meeting was held at NIH, Roorkee and all other meetings were held at CWC, New Delhi.

1.5 Consultations made and Information obtained :

Consultations were made by the Committee and the Core Group with a number of experts including Prof. Bharat Singh, Former Vice-Chancellor, University of Roorkee, ; Dr. K.G.Rangaraju, Dy. Director, Indian Institute of Technology, Roorkee ; Prof. R.J. Garde, Former Professor, University of Roorkee and other eminent scientists and engineers.

Voluminous and useful literature was collected by the Committee and the Core Group. Brief reports of the problems being faced by the State Governments were received from Bihar, Assam, Orissa & West Bengal. Titles of major reports and papers collected and used by the Committee are given at the end of the report.

1.6 Report of the Committee

The report consists of two volumes – the first volume containing Foreward, Executive Summary & 10Chapters and the second volume containing Annexures. Members of the Committee were entrusted with writing of the report relevant to their own areas of specialization. All chapters of the report were thoroughly reviewed by the Core Group. The Member Secretary and the Chairman of the Committee also subsequently perused these chapters. The Annexures mainly contain the materials that have been collected from State Governments viz. Orissa, West Bengal, Assam and Bihar. Brahmaputra Board and GFCC have also provided reports on Brahmaputra and Ganga respectively. The Morphology Dte. of Central Water Commission compiled cross-sections of some of its sites on major rivers viz. Ganga, Brahmaputra, Krishna, Godavari for working out aggradation/degradation in those rivers.

The Volume-I contains the following :-

Foreword

Executive Summary

Chapter-I	Introduction
Chapter-II	Definition of the Problem
Chapter-III	Review of Literature and Case Studies
Chapter-IV	Process of Sedimentation and Siltation
Chapter-V	Geological Factors in Siltation
Chapter-VI	Siltation of Rivers in India – Remedial Measures, their Merits, Economic, Legal, Environmental and Social Aspects
Chapter-VII	Special Problems of Siltation of rivers in India
Chapter-VIII	Research and Development in the Field and Future Directions.
Chapter-IX	Recommendations and Suggestions
Chapter-X	Bibliography

Volume-II of the Report contains the material on silting in rivers supplied by Shri B.C. Nayak, retd. Engineer-in-Chief; Secretary, Flood and Drainage, West Bengal; Secretary, Drainage and Waterways, Govt. of Assam; Engineer-in-Chief, Govt. of Bihar. Brahmaputra Board has submitted the report on silting in Brahmaputra river which has also been included in the second part. GFCC has prepared a separate note on Ganga indicating vulnerable reaches of the river amongst other things. This also forms part of the Volume II. Because of limitations of space and practical considerations it has not been possible to include all available literature and data in Volume-II.

1.7 Acknowledgement

The Committee was truly multi-disciplinary in its composition. The members, therefore, discussed any matter from different points of view. The conduct and deliberation was throughout cordial and relevant. All members were extremely accommodating and were never found not forthcoming. We express our appreciation for the work, done by the members.

The Core Group was constituted to give impetus to the report writing and therefore, it had to see the nitty-gritty of each and every aspect of the report. Inspite of their own duties, these members spared time for preparing the report. We express our deep gratitude to the members of the Core Group.

Shri S.K.Das, Member (RM), CWC and a member of the Committee retired on 30th September, 2002. Shri Gopalakrishnan succeeded him and served as member of the committee. Sri S.K. Das, Chairman, GFCC continued as a member of the Committee till Oct. 2002 and on his transfer as Member (WP&P), CWC Sri V.B. Vashista, Chairman, GFCC served as a member of the Committee. Sri B.K. Baruah, Former Secretary, Flood Control, Govt. of Assam, Sri P.K. Basu, Former Secretary, Irrigation & Waterways, Govt. of West Bengal, and Sri A.R. Ghatak, Former Hydrographic Chief, IWAI also served as members of the Committee. The Committee is thankful to these past members of the Committee for their contributions. The Committee also appreciate the assistance provided by Dr. Y.P. Sharda of Geological Survey of India.

The field formations of RM Wing provided data and Morphology Directorate under Chief Engineer (P&D) functioned as Secretariat. The Committee used Committee Room of Member (RM) as venue for its meetings. We owe a debt of gratitude to the former as well as the present Member (RM), Central Water Commission. Thanks are also due to the staff and officials under the offices of Member (RM) and CE(P&D) who facilitated the committee to carry out the works in a smooth manner.

CHAPTER-II

DEFINITION OF THE PROBLEM

CHAPTER - II

DEFINITION OF THE PROBLEM

1.0 INTRODUCTION :

The problem of siltation in Indian rivers has taken an enormous dimension. There is a general perception that due to silt deposition, river beds are rising thereby resulting in reduction of the carrying capacities of the rivers & consequent over flows causing flood. In India no systematic scientific study on the silting problems of the rivers has been carried out except for few reaches in some major rivers like Brahmaputra and Kosi. There has been suggestions to carry out desilting in some flood prone rivers and increase the flood carrying capacity of rivers. The silt thus removed may be used for construction of embankments along the banks of river. Erosion and subsequent siltation in rivers specially alluvial rivers of north India and coastal area is a serious concern as it affects the morphology of the rivers. Some of such concerns are given below :

- Since the beginning of settled agriculture, soil erosion has destroyed about 430 million ha of productive land.
- The annual global loss of agricultural land due to soil erosion is 3 million ha.
- The world is now losing an estimated 23 billion tons of soil from agriculture lands in excess of new soil formation. At the current rate of excessive erosion, the global soil resource is being depleted at 0.7 percent each year.
- For every kg of food consumed in the United States in 1977, water caused the erosion of over 20 kg of soil from all agricultural land.
- Crop productivity is reduced to zero or becomes uneconomic because of soil erosion and erosion-induced degradation on about 20 million ha each year.
- Crop yields from rainfed areas might decrease by 29 percent over the next 25 years.
- Soil erosion in Kenya during the 1970' produced an economic loss greater than the value of the annual gross national product.
- If present siltation rates continue, about 20 percent of the USA small reservoirs will be half-filled with sediment and, in many instances, their utility seriously impaired in about 30 years.
- The annual off-site damage caused by sediment eroded from the land in the United States is estimated at more than 6 billion dollars.
- Excess sediment is the major form of human-caused water pollution in the world today and exacts a heavier cost possibly more than all other pollutants combined.

Keeping in view the seriousness of the siltation problems and examining the efficacy of dredging operation, the Ministry of Water Resources, Govt. of India has constituted the Expert Committee.

2.0 MAJOR RIVER SYSTEMS OF INDIA

There are numerous rivers in India. Floods and droughts are often experienced. 40 million hectares of land is flood prone and protection has been provided to about 15 million hectares of land against floods. Flood protection has been provided by structural methods such as embankments, flood storages, channel improvements, detention basins, etc. and non structural methods such as flood forecasting and flood proofing. Flood embankments have been facing controversies dating back even from nineteenth and early twentieth centuries. The Rashtriya Barh Ayog report has dwelt upon the subject in detail. In its final conclusion, it has recommended the construction of embankment subject to proper design, construction and maintenance as per specific requirement.

The Report of the national Commission for Integrated Water Resources Development prepared in the year 1999 has dealt with River System of India in detail. Based on the physiography, the river systems of India can be classified into four groups, viz. (i) Himalayan rivers, (ii) Deccan rivers, (iii) Coastal rivers, and (iv) Rivers of the inland drainage basin. The main Himalayan River Systems are those of Indus and Ganga-Brahmaputra-Meghna systems. The Himalayan rivers receive very heavy rainfall in monsoon months and swell, causing frequent floods. The flows in the summer months are due to melting of snow and glaciers and, therefore, these rivers have perennial flow throughout the year. The important river systems in the Deccan are the west flowing rivers of Narmada and Tapi and the east flowing rivers of Brahmani, Baitarni, Mahanadi, Godavari, Krishna, Pennar and Cauvery. The Deccan rivers are rainfed and few of them are non-perennial. There are numerous coastal rivers which are comparatively small. Most of them are non-perennial. While only a handful of such rivers drain into the sea near the deltas of east coast, there are as many as 600 such rivers on the west coast. The west coast rivers are short in length and have limited catchment areas. A few rivers in Rajasthan do not drain into the sea. They drain into salt lakes or get lost in sands with no outlet to sea.

Earlier, the entire country was suitably divided into 20 river basins by the Central Water Commission. These comprised 12 major basins (having a drainage area exceeding 20,000 sq.km'.) and eight other river basins each combining a number of medium and minor rivers. However, it was seen that some areas such as the area north of Ladakh not draining into Indus and areas of Andaman, Nicobar and lakshadweep islands are not covered in the 20 river basins. In consultation with the Central Water Commission, NCIWRD reviewed the grouping of the river basins. Based on this review, the drainage area of the country has now been divided into 24 basins, which includes two basins, namely areas of North ladakh not draining into Indus and Drainage area of Andaman, Nicobar and lakshadweep Islands. The group of minor rivers of East Coast, South of Mahanadi have been divided into five basins in place of the earlier two. basins and the rivers draining into Myanmar and Bangladesh have been grouped under two separate basins, in place of the earlier one basin. The rivers of West Coast South of Tapi are grouped into one basin in place of the earlier two basins. Area of inland drainage of Rajasthan which was one of the twenty basins is deleted. The list of basins so proposed alongwith their catchment areas is given in Table 1.

TABLE - 1

MAJOR RIVERS AND THEIR CATCHMENT AREAS

S. No.	River Basin	Catchment Area, Km2	States Covered in the Basin
1.	Indus	321289	J&K, Punjab, Himachal Pradesh, Rajasthan & Chandigarh
2.	Ganga-Brahmaputra-Meghna Basin:		
2a.	Ganga Sub-basin	862769	Uttar pradesh, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh, Bihar, West Bengal and Delhi UT.
2b.	Brahmaputra Sub-basin	197316	Arunachal, Assam, Meghalaya, Nagaland, Sikkim and West Bengal
2c.	Meghna (Barak) Sub-basin	41157	Assam, Meghalaya, Nagaland,Naipur, Mizoram and Tripura
3.	Subernarekha	29196	Bihar, Jhadkhand, West Bengal and Orissa
4.	Brahmani-Baitaranj	51822	M.P.Bihar, Jhadkhand and Orissa
5.	Mahanadi	141589	M.P., Maharashtra, Bihar, Jhakhand and Orissa
6.	Godavari	312812	Maharashtra, A.P., M.P., Orissa & Pondicherry
7.	Krishna	258948	Maharashtra, A.P. & Karnataka
8.	Pennar	55213	A.P. & Karnataka
9.	Cauvery	87900	Tamilnadu, Karnataka, Kerala & Pondicherry
10.	Tapi	65145	M.P. Maharashtra and Gujarat
11.	Narmada	98796	M.P. Maharashtra and Gujarat
12.	Mahi	34842	Rajasthan, Gujarat & M.P.
13.	Sabarmati	21674	Rajasthan and Gujarat
14.	West Flowing Rivers of Kachchh, Saurashtra, Luni	334390	Rajasthan, Gujarat and Daman and Diu
15.	West Flowing Rivers south of Tapi	113057	Karnataka, Kerala, Goa, Tamilnadu, Maharashtra, Gujarat, Daman & Diu & Nagar Haveli.
16.	East Flowing Rivers Between Mahanadi	49570	A.P. & Orissa

	and Godavari		
17.	East Flowing Rivers Between Godavari and Krishna	12289	Andhra Pradesh
18.	East Flowing Rivers Between Krishna and Pennar	24649	Andhra Pradesh
19.	East Flowing Rivers Between Pennar and Cauvery	64751	A.P. Karnataka & Tamilnadu
20.	East Flowing Rivers south of Cauvery	35026	Tamilnadu & Pondicherry UT.
21.	Area of North Ladakh not draining into Indus	28478	Jammu & Kashmir
22.	Rivers draining into Bangladesh	10031	Mizoram and Tripura
23.	Rivers draining into Myanmar	26271	Manipur, Mizoram and Nagaland
24	Drainage areas of Andaman, Nicobar & Lakshadweep Islands	8280	Andaman, Nicobar and Lakshadweep
	Total	**3287260**	

Ganga, Brahmaputra and Meghna rivers flow into a common terminus before joining the Bay of Bengal; hence, Ganga- Brahmaputra- Meghna is considered as a basin, and Ganga, Brahmaputra and Meghna rivers are considered as sub-basins of Ganga- Brahmaputra -Meghna basin. Brahmani and Baitarani river systems fall into Bay of Bengal forming a common delta; thus, Brahmani-Baitarani constitute a single basin.

3.0 PROBLEMS OF EROSION AND SEDIMENTATION

Siltation or sedimentation in rivers has been the major cause of concern to humans since time immemorial. In 1976, Eckholm, contended that "excess silt is the major form of human-induced water pollution in the world today and exacts a heavier cost, possibly more than all other pollutants combined". Similar sentiments have been used to emphasis the importance of problems of loss of reservoir storage due to sedimentation, the off-farm impact of eroded sediment, the role of sediment in the transport of contaminants and various other environemtnal and operational problems associated with enhanced suspended sediment transport by water courses (Table-2). These problems have a very significant economic dimension also.

TABLE - 2

Some potential physical impacts of the increased suspended sediment loads associated with accelerated erosion

In stream effects

- Biological impacts e.g. turbidity, sedimentation, reduced productivity and species diversity.
- Recreational impacts e.g. restriction of swimming, boating, and fishing and reduction of overall aesthetics.
- Sedimentation of channels and water storage bodies e.g. reservoirs sedimentation, impairment of navigation, siltation of training structures.
- Increased abrasion of hydraulic equipment e.g. HEP turbines.

Off-stream effects

- Flood damage e.g. aggradation, increased damage from muddy water.
- Sedimentation of conveyance systems e.g. irrigation and drainage channels.
- Increased cost of water treatment e.g. increased sedimentation times, clogging of filters.
- Impairment of industrial water use e.g. reduced cooling efficiency, abrasion of pumps and turbines.
- Sealing of irrigated soils.

However, the problems associated with increased sediment loads in rivers consequent upon increased erosion within their drainage basins are now widely recognised and this recognition has been paralleled by growing evidence of greatly increased rates of soil loss and sediment yield in many area of the world as a result of human activity and particularly land use change. Table - 3, for example, contrasts rates of soil erosion documented under natural undisturbed conditions with loss occurring in cultivated areas. In all cases there is an order of magnitude increase, and in several instances the increases are even greater. A substantial proportion of the eroded material generated by this increase in both the incidence and intensity of water erosion finds its way into rivers and there are reports of greatly increased sediment yields in many parts of the world and particularly in developing countries.

TABLE - 3

Comparison of soil erosion rates under natural undisturbed conditions and under cultivation in selected areas of the world.

Country	Natural (kg m-2 year -1	Cultivated (kg m -2 year -1
China	< 0.20	15.00 - 20.00
USA	0.003 - 0.30	0.50 - 17.00
Ivory Coast	0.003 - 0.02	0.01 - 9.00
Nigeria	0.05 - 0.10	0.01 - 3.50
India	0.05 - 0.10	0.03 - 2.00
Belgium	0.01 - 0.05	0.30 - 3.00
UK	0.01 - 0.05	0.01 - 0.30

4.0 PHENOMENA ASSOCIATED WITH SILTATION

It will be important and relevant to discuss the various phenomena associated with siltation and sedimentation. Sedimentation embodies the processes of erosion, entrainment, transportation, deposition and compaction of sediment. These natural processes are extremely complex and have been active throughout the geological times resulting in denudation of earth's crust and shaping the present landscape of the world. The principal external dynamic agents of sedimentation are water, wind, ice and gravity which bring about the disintegration. The detachment of particles in erosion process occurs through the kinetic energy of raindrop impact or by forces generated by flowing water. Once detached, both entrainment and transportation depend on shape, size and weight of the particle and the forces exerted on the particle by the flow. Deposition occurs after the forces on the particle diminish or reduce.

There are number of ways by which the sediment is generated. However, sediment is generally generated by the disintegration of the earth's crust chiefly by the action of temperature, running water, wind, ice, vegetation, movement of animals and of men. Sun is the chief agent of change on the surface of earth. Alternate heat and cold and abrupt changes of temperature, resulting in uneven expansion and contraction of rocks containing minerals of different coefficients of expansion and contraction, break huge rock masses into pieces. Mechanical action of wind on rock surfaces results in formation of sand. Damp air containing oxygen and carbon dioxide react with the minerals of certain rocks to form friable compounds like oxides, hydrates and carbonates, Which are easily transported by rain water to rivers. Even the hardest rocks disintegrate under chemical action of air and water.

Rainwater also helps to disintegrate the rocks by entering and freezing in the joints and crevices 6f rocks under low temperature, and on expansion, breaks open the rocks. Huge landslides occur due to lubricant action of water among other causes. Constant flow of water widens the subterranean channel due to erosion of side banks and dissolving of more and more rocks. This is more pronounced in limestone zones. Moving of ice in the forms of glacier and avalanches on slopes deepens and widens the valley and eroded material is carried in rivers as sediment. Vegetation normally protects the soil from erosion but this can also increase erosion by extending its roots in cracks and opening of rocks and burst them open by exerting greater pressure which starts the initial process of disintegration. Acidic sap of roots of some of plants react with the rocks.

Burrowing animals such as rabbits, rats make the earth soft. Earthworms and ants also help in the process. This makes the ground weak which becomes an easy prey to disintegration. Man's activities also aggravate the denudation in many ways, construction, excavation, quarrying, tunneling, road construction, deforestation, mining etc., which are in fact a part of developmental works, directly aid erosive forces. Ploughing of lands and wrong methodology of cultivation also result in disintegration of soil.

The rate of erosion is directly dependent on the nature of rock or soil in the basin or catchment, climatic influence, terrain, physiography and geology of the land. There are various types of erosion which contribute to the process of sedimentation. These are (a) sheet erosion (b) gully erosion (c) stream channel erosion (d) flood erosion (e) construction erosion and (f) mining erosion.

The main agencies transporting the sediments are gravity, water, wind and ice. Water acts when the rain falls on the mountains and carries the rock material into the bed of the stream. On the sloping land, naked or bearing vegetation, unabsorbed water flows as runoff over the surface. It is this runoff water that carries the soil and sediment material. In the head reaches, the stream load consists mostly of coarser materials such as boulders, rocks and gravels. In the plains, the size of sediment charge is small but the total load is very large. The size of the materials goes on decreasing as the distance from source of stream increases. Sediment transportation by streams takes place by traction, saltation, suspension and solution.

At very low velocities no sediment will move but at higher velocities individual grains will roll and slide intermittently along the bed. Dragging or rolling of sediment along the bed is termed as traction. The coarser and heavier particles which move sometimes in suspension in the bottom layer of water and picked up from the stream bed constitute the material which is said to move by traction. This movement is more or less horizontal and occurs in the close proximity of the bed.

At higher velocities some grains will make short jumps, leaving the bed for short instants of time and returning either to come to rest or continue motion of the bed or by executing further jumps. The movement of bed material in a stream in leaps and jumps is called saltation. This is restricted to the bottom layers and mostly deals with the materials constituting the stream bed and is perhaps the coarser grade in the stream.

If the velocity of flow increases still further, the jumps executed by grains will become more. The frequent and some of the grains will be swept in the main body of the flow, q_y upward component of turbulence and kept in suspension for appreciable length of time. Sediment particles which flow with the stream over a considerable distance in suspension in the above manner are known as suspended load of a stream. Such suspension processes continues unless a change of gradient of stream or change of velocity occurs. The grade and the quantity of sediment in suspension varies along the depth of the stream and with turbulence.

The stream as it flows through the different regions and strata carries with it soluble salts in the form of solution in addition to the suspended matter. These, however, being in solution do not create problems except in case of floodulation.

While material is transported in suspension, saltation and rolling and sliding or traction on the bed is also occurring, so all the three modes of transportation occur simultaneously. Apparently, it is difficult to separate these three modes of transportation and therefore, the three different kinds of sediment loads. In practice these difficulties are avoided by introducing the term "bed load" which is defined as material moving on or near the bed. The total load practically thus comprises of bed load and suspended load.

From the summit of the mountains to the sea, the size of the material constituting the river bed goes on diminishing from rough masses of large irregular stones/boulders through gravels to fine sand and clay. The upper reaches of the river transport large rock pieces which are least regular in shape. In the head reaches the rocks of even 2 metre to 3 metre diameter may roll on the bed particularly during high velocities in floods. As the slope becomes flatter in lower reaches the size of the bed material carried is smaller, as the coarser grains will settle on the way, in the upper reaches. With the further decrease in slope, the gravel also stops moving and the bed load consists of coarse sand and gravel Towards the end of the stream, the bed is made up of fine sand and clay. As the river emerges out of the foot hills of the mountains, the boulder and the shingle stage of the river ends and the alluvial stage starts. The river slope becomes so flat after some time that the gravel and shingle do not move aqy further.

When the sediment load of a river, stream or channel is more than the carrying capacity of the channel or when the velocity of the channel becomes very low, deposition of the sediment takes place. This is evident in canals where the slopes are flatter or at the mouth of river entering into reservoirs. The Products of erosion may be deposited immediately below their sources or may be transported for considerable distance to be deposited in channel on flood plains, lakes reservoirs, estuaries or in ocean.

The deposition of sediment may either be beneficial or may create new and serious problems depending on its nature, quantity and quality. Erosion may cause serious on site problems for agricultural lands by reducing the fertility and productivity of soils. Sediment in transport may affect the quality of water making it unfit for industrial use or for human consumption. The deposition of sediment in irrigation and drainage canals. In navigation canals and flood ways, in reservoirs and harbours. on streets and highways and in buildings becomes a matter of nuisance and inflicts a high public cost in its maintenance and removal.

5.0 CLASSES OF EROSION

Mainly there are two classes of erosion - geologic erosion and accelerated erosion. Accelerated erosion may be caused by anyone or more of the following:

i) Agricultural activities.

ii) Urbanisation

iii) Road and highway construction.

iv) Mining operation.

v) Gully erosion -altering runoff conditions.

vi) Stream/river bank erosion.

Any type of erosion process as stated above is a potential source of sediment contribution. Geologic erosion has been a continuous process since ancient times. As a result. rivers have silted up and changed their courses to unimaginable extent. The Ganga and its tributaries for instance are heavily laden with sediment. Accelerated erosion is defined as increased rate of erosion over the normal geologic erosion brought about mostly by man's activity. The erodibility of natural material can be altered by disturbing the soil structure through ploughing or other tillage activities. The protective canopy can be hanged by removing existing one and planting another. The runoff conditions also get changed by construction of structural works. All these activities can have profound influence on erosion. Of many man made changes that have influenced the erosion processes, agricultural activities lead all the rest resulting in accelerated erosion and sediment production. Accelerated erosion from the wide spread use of land. specially in quest of food. has deteriorated the lands and extinguished many civilizations. Only Indus valley in India, and Nile valley in Egypt remain sustained till today. The productivity of the soil is deteriorated by this type of erosion. Urbanization processes involving construction and developmental works result in opening up of large tracts of land for excavation and continuous exposure. This increases the sediment production rate manifold. With increase in population and need for urbanization in tracts of land, this factor becomes more prominent with respect to erosion and sediment production. Road and highway construction results in exposure of excavated and loosened structure and increases the rate of sediment production. The excavation creates unstable slopes, improper drainage etc. Mining operations may introduce large volumes of sediment directly into stream. This results in pollution of air and water quality. Gully erosion constitutes a significant hazard in the living conditions. Gullying establishes land and slope of the country.

It is estimated that about 6000 million tons of soils are eroded every year in India as a result of sheet erosion. From about 80 million hectares of cultivated lands, 6.2 million tons of nutrients are carried away every year. This is much greater than the quantities we are using at present. Gully and ravine erosion ravage 8000 ha. annually. 0.5 percent ravine catchment is eroded. Annual damage to the table land accounts for Rs. 120 million. Ravines are mostly found along the rivers of Yamuna, Chambal, Sabarmati, Mahi, Gomti and in the catchments of the Mayurakshi, Kangsabati in the eastern red soil region. As a conservative estimate the country is losing a total output of 5 million tons of food grains annually. The shifting course of river Kosi by 112 kms from East to West between 1738 and 2000 a period of 262 years is a classic example of stream channel erosion. In Himalayan regions, landslides are extensive and result in poor communication, dislocation of public utilities and sedimentation of downstream reservoirs.

6.0 MOVEMENT OF SEDIMENT :

As already stated above, sediment is transported in suspension as bed load rolling and sliding along the bed or/am suspended load or inter-changeable by suspension and bed load. The nature of movement depends on the particle size, shape and specific gravity in relation to the a5sociated velocity and turbulence. Under some conditions of high velocity and turbulence e.g. high flows in steep gradient mountain streams, big boulders/cobbles are actually carried in suspension. Conversely, even silt size particles may move as bed load in low gradient, low velocity channels. Though the total damages due to sediment transport in no way approach those due to erosion and deposition sediment, even in transport as bed load or in suspension, may create severe problems.

7.0 DAMAGE BY IMPINGEMENT OF SEDIMENT LOAD :

Streams carrying .cobbles/boulders can severely damage bridge piers and abutments and trestle piers on torrential streams by chipping away unprotected concrete. Paved flood channels that carry coarse sand and gravels are subjected to wear and tear and need periodic repairs. Trees, fences, telephones/electric poles and lines in the flood path are other targets of damage. But the chief damage due to the impingement of finer sediment is caused to turbine blades runners, and pumps. Damage is normally caused by the velocity of impingement and by the accompanying abrasion. Hydroelectric equipment receive considerable damage, resulting in recurring and large expenditure on repairs and replacement. Suspended sediment affects the light penetration in water and reduces the growth of microscopic organisms on which insects and fish feed. There is a definite effect of suspended sediment on the size, population species of fish. The growth of the fish is not freely possible in muddy water. This is an important aspect of sediment in suspension. Most people have natural antipathy for "muddy streams". In such cases, purification of water for human consumption costs large amounts.

8.0 DEPOSITION OF SEDIMENTS

All eroded material do not enter stream systems. The products of erosion may be deposited down stream of their sources immediately or may be transported for a considerable distance to be deposited in channels or on flood plains, lakes, reservoirs, estuaries or oceans. Considerable damage can be caused depending on the amount, character and place of deposition. All sediment deposition is however not necessarily injurious or beneficial. The percentage sediment reaching the ocean has got very little impact on mankind. But this quantum is also widely variable.

The sediments that get deposited in flood plains create numerous problems. They may completely bury crops. Unfertile material reduce the fertility and long-term productivity of flood plain soils. The surface drainage in lands prone to floods is impaired by deposition of finer material behind the formation of natural levees of coarse material. In such cases such lands become swampy ground, and permanently wet in initial stages and later is converted into standing water with desolate and dead wood/snags. Such instances have been evident in Assam Valley, and Gangotri Delta. There are also in-stances where rail road communications are frequently disrupted and serious problems are created in the developmental works, needing high clean up and maintenance cost.

The deposition of sediment in drainage ditches, irrigation canals, navigation and natural stream channels creates serious problems in loss of services and clean up costs. Sediment deposits in ditches result in the raising of water tables and damage to crops. Deposits in ditches under low velocity are fine grained. This is inherently fertile and promotes rapid vegetative growth. This in turn slows down the flow and results in higher rates of deposition and damage. Sediment in ditches reduces the rate and volume of water delivered to irrigated area in required amounts resulting in serious cro1.1p damage. Deposition of coarse grained sediment into irrigated areas reduces soil fertility while colloidal sediment reduces permeability both of which result in stagnation and reduce productivity of irrigated land. Clean up and maintenance of irrigation ditches and reduced productivity represent sizeable damage.

The sediments deposited in navigable channels, waterways, harbours and mouth portion of rivers falling into sea have to be flushed out or removed periodically. In USA the amount of sediment dredged each year from the channels and waterways is eqùivalent to the cost quantity of Panama canal excavätion. Flood water damage is greatly aggravated by the deposition of sediment in channels due to reduction in their capacities and consequent overflows. Proper solution in the above case will be the accelerated erosion and control sediment movement at source.

CHAPTER – III

REVIEW OF LITERATURE AND CASE STUDIES

1.0 INTRODUCTION

Flooding is a recurring phenomenon in India. As per the estimate of the National Flood Commission (Rashtriya Barh Ayog, 1980) the area liable to floods in India is 40 million hectares. The area provided with reasonable protection was 14.4 million hectares as on March, 1993 (CWC, 2001). The average area and population affected every year during the period 1953-99 were 7.62 m.ha. and 33.28 million people respectively. In 1978 a maximum area of 17.5 m.ha. was affected by floods. The flood prone areas mainly lie in the Ganga- Brahmaputra plains as well as in deltaic regions.

The floods are caused by intense rainfall generating run-off much above the capacity of the land and rivers to drain. The floods are accentuated by geomorphic causes such as channel migration, meander growth and avulsion, backup into tributaries, rise in river channel due to sediment deposits after earthquake and landslides, glacier lake outburst and drainage congestion. Catastrophic floods are caused by dam and embankment failures and synchronizing in time of flood causing events like intense rainfall, release of water from reservoirs, storm and tidal surges.

The approaches to managing floods can be broadly grouped into structural and non structural. Under structural approach comes the following activities : control/protection works such as embankments and flood walls, reservoirs, natural detention basins, channel improvement, emergency flood ways, river diversions, inter basin transfer, bank stabilization and anti-erosion methods and underground storage reservoirs. Through watershed management and soil conservation measures floods of smaller magnitude can be moderated. Generally structural approach is adopted to manage the floods. The increase in flood damages in recent times even after structures are completed necessitated a rethinking on this approach. Emphasis is also given to non structural approaches to flood management. The non structural approach includes flood plain management, structural changes in buildings, flood proofing, disaster preparedness and response planning, flood forecasting and flood warning, emergency measures such as evacuation flood fighting and public health measures, flood insurance, relief and rehabilitation.

The history of floods, particularly catastrophic floods in recent times, clearly brought out the inadequacy of any one method to minimize the loss due to floods in each flood prone area. A combination of approaches and methods, appropriate to each flood prone area need to be evolved, implemented and reviewed not only to minimize the loss of human lives and properties, but also to reduce the intensity and duration of suffering of the flood affected people and also provide means for their rehabilitation.

In this context the term of reference of the Committee viz. desilting as a technical means to minimize magnitude of floods in rivers is looked into by studying various desilting works carried out in India and abroad.

2.0 FLOOD MANAGEMENT IN CHINA

China, like India, experiences frequent floods. The two largest rivers in China Huang He (Yellow) and Chang Jiang (Yangtze) rivers cause enormous floods in their lower reaches. The 5464 km long yello river the second largest in China runs through 11province level administrative zones before emptying into the Bohai sea in Sandong province The floods wash mud and sand into the river, turning it into literally an yellow river. The Yellow river at Sanmenxia had a flow of 36,000 m3/sec in 1843, nearly twenty five times its average flows (Smil,V.1982).The Yellow river also changes course frequently. From 602 BC to present the river course made at least 5 major large scale changes. The last change occurred in 1855.

The southern and eastern parts of China are more vulnerable to floods. About one-tenth of China's territory inhabitated by nearly two-thirds of the population is below the flood level of major rivers. The enormous silt load brought down by major rivers raises the river beds and lake levels, resulting in increase in area vulnerable to floods. The rivers draining the Loess Plateau carry enormous silt load. The river's silt load has increased from about 1.3 GT in early 1950s to 1.6 GT in the early 1980s. It is estimated that in a decade the annual river bed build up has amounted to about 400 Mt and the average river bed rise has been 1 m.

The rivers originating from mountains in the south & west and passing through deep gorges carry silt load between 2.2 to 2.4 GT every year, raising river beds and lake levels in Hubei and Hunan. Some of the lake's water level during the rainy season is approaching the height of the catastrophic flood 1954 and exceeding the danger level at sixty eight different places. Elevation and strengthening of dykes cannot be an effective permanent solution. Moreover, more dykes and spill over basins along the Chang Jiang (Yangtze) are now able to withstand floods of only a ten to twenty year frequency; a repeat of the 1954 flood assessed by the Chinese water management aspects as one of for 9 year probability could lead to a displacement of up to seven million people and to unprecedented economic loss.

Concentrated heavy prolonged rain spell, heavy silt load and level terrain cause floods in China. In nineties there were 5 major floods (Table-1). The worst was in the year 1998 when 25 million hectares of land was affected by floods, damaging nearly 21 million houses, causing 3500 deaths and an economic loss of 32 million dollars.

Table - 1

Flood and Water-logging Disasters in China

		1990	1991	1994	1995	1998
1.	Area affect m.ha.	11.8	21.6	N.A.	2.7	25
2.	Houses and buildings damaged (No. in million)	1.3	4.979	8.5	6.0	21
3.	Lives lost	3535	5113	1100	650	8500
4.	Length of damage to dikes (Kms.)	14,000	N.A.	N.A.	N.A.	N.A.
5.	Total Direct Economic losses (billion yuans)	23.9	77.9	-	-	$ 32 millions

Over centuries China has been making efforts to combat floods. Flood management in the Haiho river basin illustrates the Chinese approach to flood management. Haiho river basin, lying to the north of the Yellow river, drains an area of 265.00 sq.km., mostly in Hopie province of China. The capital of China Beijing and industrial town Tientsin are located in the basin. This basin experiences floods very often. The worst flood occurred in 1939 and 1963. After the devastating floods in 1963, a plan was mooted to control the floods in Haiho river basin.

In 10 years from 1963 to 1973 more than 80 large and medium and 1500 small reservoirs, 34 trunk waterways with a total length of 3900 kms, 4200 km. long flood prevention dykes were built. Over 270 tributaries and 150,000 canals and ditches were dug or dredged. 60,000 bridges, water locks and culverts were erected along the streams. Thousands of people were pressed in to the work. Half a million cubic meters of earth were moved manually.

The plan to manage floods in Tzuya river consisted of digging two rivers and building two dykes. A ditch of 20 meters depth was to be dug on the northern bank of the 3 km wide river. The earth removed was used to construct a dyke to the north. Beyond a 2 km wide beach south of the ditch a dyke was constructed. Apart from these a unified plan for flood protection consisting of six river control sub-projects was mooted. They were river excavation, dyke erection, road making, bridge building, land reclamation and tree planting. (Foreign Languages Press Peking, 1975)

The Chinese government is now making a comprehensive approach to the management of floods and silt reduction in the next 10 years. To the extent feasible floods are stored in upstream reservoirs. One such project under construction is the Three Gorges Project on the Yangtze river. It began in 1992 and is likely to be completed by 2010. In the middle reaches of the river basin flood detention and flood storage areas are constructed.

By 1999 soil conservation efforts were made in upper reaches in 1/3 of land area (177,000 km^2) on the Loess Plateau, in the Yellow river basin. In middle reaches 141300 km^2 of land have been treated. This has resulted in a reduction in silt load to 300 million tons. In Shandi province, soil conservation works over 20,000 km^2 reduced the sand flow from 530 million tons in 1950 to its present 290 million tons.

Other methods of flood control are also being tried in China. In July 2002 Chinese scientists and engineers carried out an experiment to flush Yellow river silt down to the sea using artificial flood waves. China has opened a web site for question and answer on different methods of flushing silt.

Hydraulic modelling to produce flood routing and arrival time and working out the best scheme to close up breach quickly to mitigate possible losses and damages and give people a chance to evacuate are also being experimented.

3.0 RIVER DREDGING IN BANGLADESH

Bangladesh experiences floods every year. The rivers are also used extensively as navigational channel. The government of Bangladesh has been trying to control sedimentation of river channels by dredging. After massive flood experience in 1954 a fleet of dredgers were procured by Bangladesh government with foreign assistance and the Water Development Board was set up to regulate floods. After nearly 45 years the country has only 24 half capable or obsolete dredgers in operation. Therefore the tasks of river training or dredging the rivers to improve navigability and reduce flooding prospects could be little achieved over all these years. The present government took upon a project of dredging 530 kilometers of river ways.

Under UNDP project, the Department of Sedimentation of the China Institute of Water Resources and Hydropower Research, is doing a feasibility study of desilting of 20 medium and minor rivers in Bangladesh.

4.0 FLOOD MANAGEMENT AND DREDGING PRACTICES IN USA

In the United States of America many projects have been undertaken to control floods and to keep the river channels free from sediments. In spite of two centuries of implementation of various projects USA still experiences severe floods and problems of river siltation. The severe floods that occurred in 1993 and delivered dredging project or described the following sections to highlight the complexity of flood management and river dredging.

4.1 Mississippi River

The Mississippi is one of the largest river systems in the world, draining 6,215,000 sq. km. area in the mid west of United States of America. Since the early 18th century efforts were on to manage the Mississippi river system. Navigation and preventing destructive floods have been the major objectives of management of Mississippi river system. The approaches to flood control were through building levees and flood walls along the river banks, strengthening bends, dredging channels, removing islands and backwater areas, authorized construction of flood ways to divert peak flows and hold down river levels in the main channel during times of floods and construction of flood control reservoirs. The physical structures constructed to manage the river system include 3200 km long earth levies, about 200 flood control reservoirs, thousands of stone wing-dykes in the channel and straightening of the river course which made the Mississippi shorter by 240 km. The cost of flood control measures was over $ 10 billion and requires $ 180 million an year to maintain - (A.A.Jones, 2000).

The Mississippi is navigable from the delta to the Falls of St. Anthony in Minneapolis and connects with the Inter-coastal waterways in south with the Great Lakes – St. Lawrence Sea Way in the north by way of Illinois Waterway channel improvements have facilitated a marked increase since mid 1950's after a long period of decline.

Thus the controlled river and navigation facilities initially acted as a catalyst of growth and later encouraged activities in vulnerable flood plain and reclaimed wetland areas.

Mississippi river basin landscape once characterized by deeply rooted prairie grasses, soils high in organic matter and numerous wetlands providing temporary storage areas for storm water today has been transformed into a land which discharges water faster into the natural channels raising the flood stage to a higher level and river channels cut off from their flood plains. People live adjacent to flood controlled structures, mainly on levees with a false sense of security against floods. Their faith in them was shattered by the floods for three months from June to August in the year 1993. In 1993, in the span of about four months, floods in the Mississippi river basin killed 50 people, left another 70,000 homeless and caused more than $ 15 billion in property damage (WWF, 1994).

The 1993 floods were not unusual. Large floods have occurred on the Mississippi in 1844, 1883, 1892, 1902, 1908, 1909,1927, 1944 and 1973." The effects of the 1993 floods were exacerbated by precipitation of unusual duration and intensity, structural alterations of the river channel and flood plains and drastic reductions in the capacity of the river basin landscape to retain water where it falls.

The Great floods of 1993 were unusual in form of precipitation amounts, record river stages, extent of floodway, persons displaced and property damage and flood duration.

These floods were the result of cumulative antecedent precipitation conditions that prevailed over the area beginning from July, 1992. Above normal precipitation occurred over most of the region. There had been an excessive winter snow pack in Rocky Mountains. In the upper Mississippi valley from April through June an average of 410 mm rain fell which was 130 mm more than the normal over 18 stations June to July precipitations had a return period of over 100 years. These three month rains occurred over already water logged ground and high stream flows and reservoir levels. Naturally the floods were devastating.

The Mississippi river at St. Louis was above the flood stage of 9.14 m from 5th July to 10th August for 36 consecutive days. The flood stage surpassed the previous record of 13.17 m from 17th July to 8th August reaching a maximum of about 15.0 m on 1st August, 1993.

The same was the case in the flood stage of the Mussouri river at Konsas. The new record of about 14.5 m was observed on 27th July. (WMO, 1993)

Huge and prolonged floods along the upper Mississippi and lower Mississippi rivers in 1993 stimulated intensive re-examination of efforts to manage the Mississippi river system.

One such effort was initiated by WWF (World Wildlife Fund). WWF organized three workshops in order to incorporate public input at the earliest stages of post flood policy formulation. A broad range of community residents as well as local, state and federal government officials attended the workshops. They deliberated on case histories and on the document titled, "Federal Programmes obtaining Flood Plain Management Alternatives" prepared by the Inter agency Flood Plain Management Review Committee. The three federal strategies included wet land restoration; casement and acquisitions of rural land; and flood proofing elevation and relocation.

The participants at the three workshops agreed on three principal points :-

i) Watershed management should be the focus of any flood damage reduction strategy. A comprehensive flood damage reduction plan must manage water from the time it hits the ground. Any plan that evaluates only the river channels and flood plains will produce a superficial solution that will fail to reverse the current trend toward increased frequency and severity of floods and increased flood damages.

ii) Local governments and communities should have more responsibility and control over flood plain and watershed management, but this control should be exercised through a coordinated, inter-governmental approach. Participants expressed the concern that incentive programs for environmental protection and restoration and programs that facilitate local involvement and interagency coordination are drastically under funded.

iii) Government agencies at the local, state and federal levels should actively coordinate their activities. Coordination should be focused primarily around specific watershed or ecosystems and geared toward reducing conflicts in approaches, increasing compatibility of activities, and eliminating duplication of efforts. Flexibility should be built into government programs.

In January 1994, shortly after the first workshop was held, the White House Office of Management and Budget and the Office on Environmental Policy jointly convened an Interagency Floodplain Management Review Committee under the direction of Brigadier General Gerald Galloway. The Committee was appointed to undertake an intensive review to determine the major causes and consequences of the 1993 Mississippi River floods; evaluate the performance of existing floodplain management and related watershed management programs; and make recommendations as to what changes in current policies, programs, and activities would most effectively achieve risk reductions, economic efficiency, and environmental enhancement in the floodplain and related watersheds.

In July, 1994, the Committee released its final report to the White House (Interagency Floodplain Management Review Committee, 1994). The following recommendations contained in the report reflect input from the WWF workshops:

- Establishment of an inter-agency task force to formulate a comprehensive approach to watershed management;
- Expansion of conservation and voluntary acquisition programmes focused on critical lands within watershed;
- Increased funding for collaborative planning activities by federal agencies on a watershed scale;
- Flexibility in use of programmed funds in emergency situations;
- Integration of federal flood response; and
- Evaluation of the effect of natural storage in wetlands on mainstream flooding.

WWF strongly supports these recommendations, and believes that more emphasis should be given to locally driven, watershed focused approaches to flood damage reduction.

A variety of solutions are needed to reduce future flood damages in the upper Mississippi River basin. No single solution will be appropriate for every location. The approach to flood damage reduction that is likely to yield the most benefits at the lowest cost in many parts of the basin is one that retains water on the landscape rather than transferring it quickly downstream. This approach requires the restoration of some of the pre-settlement characteristics of the watershed, such as permanent vegetative cover, an abundance of wetlands, and soils with high organic content that help to reduce flood peaks and contribute to stream flows during dry seasons.

4.2 Delaware River Federal Shipping Channel Dredging Project

Delaware shipping channel is an important navigational channel in USA. Since 1800 dredging of Delaware river is being carried out. The initial 18 feet deep channel is now 40 feet deep. In 1992 the Congress authorized the deepening of Delaware river to 45 feet, from Philadelphia harbors to the mouth of Delaware bay. This is a total distance of 103 miles, 33 miles are already at 45 feet deeper.

To deepen the channel, 29.3 million cubic yards of material must be removed. The project features will cost $311 million. Congress provided $40 million dollars towards construction since fiscal 1999. Pre construction engineering design phase costed $7 million. Currently 5 million cubic yards of material are dredged. Annual maintenance dredging will increase by 1.1 million cubic yards after completion of the project.

Now the River project, being executed by U.S. Corps of Engineer was suspended in April, 2002 after the General Accounting Office raised questions about the Corps contention on the cost benefit.

4.3 Other Schemes

Union of British Columbia Municipalities Resolution No. B69 urged a cost-effective manner of dredging rivers and streams be permitted under a regulated process. Mutually agreed broad based operating plan after 1993 floods disapproves construction of dykes. According to the British Columbia Municipalities dyking systems encourage development in hazardous areas and these structures are prone to failure or overtopping and that the planning and regulation of development in the flood plain is a more effective processes for reducing overall damage from flooding.

5.0 FLOOD MANAGEMENT IN AUSTRALIA

Agricultural and Resource Management Council of Australia and New Zealand reviewed the flood plain management in Australia after a series of flood events occurred in 1990s. The flood plain management in Australia passed through four successive phases of practices. Structural works were the predominant method till 1970s. When these measures were inadequate in dealing with larger flood, planning the flood plain was given importance in 1970s. When even this did not provide protection against floods, flood emergency management was advocated in 1980s. After the devastating floods in Bogan river floods in April 1990, Australia adopted a policy of all-embracing planning. The Standing Committee on Agriculture and resource management contended that "Despite the best flood plain management and defence and evacuation efforts, floods larger than the design flood event at times much larger can and will occur.

6.0 BIRMINGHAM FLOOD PROTECTION PROJECT – RIVER TAME

R.C.Ward in his book Flood studies mentions about the rate at which channels will revert in their pre-improvement conditions will depend on a large number of variables within and outside the channel itself but is often quite rapid.

Nixon 1963 referred to the River Tame enlarged in 1930 as part of Birmingham flood protection project which had reverted to near its original size by 1959. This means that there is always the need for costly maintenance like dredging and weed control, entailing expenditure which is roughly proportional to the amount of channel improvement at least in unlined channel.

Maintenance costs alone usually set a comparatively low limit to the level of protection afforded by channel improvement schemes in agricultural areas.

Floods – A Geographical Perspective Roy Ward – 1978.

7.0 CASE STUDIES IN INDIA

The Brahmaputra is one of the largest rivers in the world having a catchment area of nearly 580,000 sq.km. in Tibet, Bhutan, India and Bangladesh. At Pancharatna the average water yield of Brahmaputra is 50 Mha.m. and the observed sediment yield (allowing 15% bed load) from 1978 to 1991 is 527 million tons per year(990 tonnes/sq.km.) The catchment area of Brahmaputra at Pancharatna is 5,33,000 km sq. Among the rivers of the world, Brahmaputra occupies the third position in terms of sediment load.

Brahmaputra Board has brought out an excellent report on siltation based on the analysis of 65 cross sections of Brahmaputra spanning over a length of 600 km for the years 1957,1971,1981 and 1989. The cross sectional area of flow, width of the river and average depth of flow have been analysed.

Based on this study the Brahmaputra Board concludes that large quantities of sediment which entered the Brahmaputra river system at its upstream end , after the 1950 earthquake moved downstream till about 1971 and hence deposition is indicated during this period. After 1971 the sediment is eroded from the bed and the bed has gone down at a decreasing rate up to 1981 and has started aggradations in the period 1981 to 1988-89. The high floods of 1987 and 1988 brought down heavy sediment load. This resulted in sediment deposition and 1.35 m of aggradations in Dibrugarh reach has been noticed. Thus aggradations and degradation in a reach are not steady and continuous phenomenon but are event specify and temporal.

The examination of the variation of bed levels in years 1971,1977 and 1981 over the level in the year 1957 indicate that the average depth has increase in rest of the reaches.

The Brahmaputra river has braided channels in most of its traverse through the plains of Assam and has a width varying from 3 km to 19 km. Due to excessive sediment change, there is constant shifting of these channels and formation of sand shoals. The river has a tendency to shift laterally more to the south. Because of these processes any desilting exercise on Brahmaputra will have little impact either on the overall reduction in sediment load of the river or on the flood carrying capacity of the river.

The State Flood Control Department did conduct dredging operation on the river bed in mid seventies. But the excavated channel was filled up during the next flood season. Therefore, the conclusion of the Board of Consultants and Technical Advisory Committee not favouring dredging should be respected.

7.1 Desilting Projects in Tamil Nadu

Tamil Nadu government is implementing a massive scheme of desilting of rivers, canals, tanks and drainage structures. This scheme was started in 1997-98 initially in the Cauvery delta and later was extended to other areas in Tamil Nadu. Till 2001, 907 tanks and 10,637 km. length of rivers and canal and drainage structures have been taken up for desilting at a cost of Rs. 178.65. The Public Works Department of Tamil Nadu plans to rehabilitate 482 tanks at an estimated cost of Rs. 53.84 crores.

In Cauvery delta silt gets deposited especially during floods in rivers, drains and channels. In addition the growth of Ipomea in the bed of irrigation and drainage sources obstructed the free flow of flood waters. Till 1996-97 silt and Ipomea in rivers, channel and drains were removed annually at problem sites. In 1997-98 government of Tamil Nadu sanctioned 154.22 crores to silt the rivers, drains channels and tanks in Cauvery delta for a length of 4590 km., 12600 km and 724 nos. respectively. By 2002, 10,610 km of water channels and 355 tanks were desilted at a cost of Rs. 111.971 crores.

The desilting works were carried out by deploying men and machine for a depth of 0.60 m to 1.50 m and width 40 to 50 m. The work was carried out during the closure period during March to June only.

According to the P.W.D. after implementing the project, submergence of 2.97 lakhs of land and damages to roads and buildings are averted during floods.

(Chief Engineer, PWAD, WRO, Tichy Region: Evaluation Report on Desilting works in Cauvery Delta System).

Another project, in progress is "Rehabilitation of Chennai Waterways" by removing silt and sludge deposited in various water ways of Chennai at a cost of Rs. 300 crores. The following works are being executed; desilting and re-sectioning of all water ways and drains within the metropolitan area of Chennai, construction of flood defences retaining walls and culverts where required and formation of flood bank. After rehabilitation and resettlement of slum dwellers the work on the main Coocum river in Chennai city will be taken up. The project is likely to be completed in 2003-04 (Govt. of Tamil Nadu, P.W.D. Irrigation and Buildings Policy Note 2002-03 Demand No. 38, Chapter-26, Internet)

7.2 Damodar Valley Corporation

One of the earliest attempts in independent India to river management and area development was the initiation of Damodar Valley Corporation. Flood moderation was an important objective of this project. In the first phase of this scheme four dams Tilaya, Konai, Maithon and Panchat Hill having a reservoir capacity of 0.1845 m ha.m. were constructed to control floods.

Apart from the construction of reservoirs, soil conservation and watershed management programmes were taken up in order to control the sediment flow into the reservoirs. The combined activities could moderate the flood generated in the upper reaches of the Damodar. The moderation of designed flood is 2.5 lakh cusecs.

Floods generated from1720 sq.km. of uncontrolled catchment drainage area upstream of Rhondia and lower Damodar are not moderated. If the floods are more than the drainage capacity of lower Damodar, devastating damages occur as in the year 1978, 1989 and 2000. The drainage capacity of lower reaches of the Damodar has been progressively reduced due to encroachments and growth of vegetation in the channels and deposits of silts. The tidal surges further aggravate the flood problems.

Considering all these facts the lower Damodar Investigation Committee (1956) had called for "proper unified development of the entire lower valley as a whole, instead of solutions of individual problems for local and short term benefits. It also laid great stress on the conservancy of the river channel and recommended that "concentrated flushing doses should occasionally be released down the river in the interest of the conservancy of the river channels.

7.3 Erosion And Sedimentation Problem in river Kosi

National Institute of Hydrology has reviewed the problem of erosion, sedimentation and flooding in river Kosi. The high silt load of the Kosi river is mainly due to the heavy erosion in catchment area which lies in Nepal and the bank erosion in the plains of Bihar. Heavy sheet erosion intensive gully erosion, land slide, soil erosion due to faulty irrigation channels and alignment of hill roads across the contiguous valley contribute to the generation and transportation of heavy silt load on the river.

The problem of aggradation of the Kosi before and after the construction of Kosi Barrage at Hanumannagar and floods embankment in the year 1963 was analysed and has continued since then. The reaches 23 to 25 km, 33 to 38 km and 80 to 81 km came under attack subsequently.

7.3.1 Study about the aggrading/degrading trend of the river

After the completion of the Barrage at Hanuman Nagar in the year 1963 and completion of embankments both on upstream and downstream of the Barrage, the tendency of the Barrage for inducing siltation, particularly on the upstream in the silt pocket and the toe water was apparently evident. Because of the cross flows and the drifting of the silt along the cross-sections of the river even on downstream, a general impression was conveyed by the silt deposits, particularly after the monsoon, that the river is showing a tendency of aggrading the bed. The Kosi Board of Consultants, however, wanted to have a systematic and scientific study to stop this trend based on analysis of the river bed data.

The aggrading and degrading trend of any river channel is actually the function of its discharge, low as well as peak, the sediment load and the grade of the bed. Unless detailed analysis is carried out about all these parameters deciding finally the aggrading and degrading trend of a river, it may perhaps be an error to judge and conclude about the trend of this river flow.

7.3.2 The effect of construction of embankment on the river bed

In order to determine the effect of Kosi project, a study was carried out at the Indian Institute of Technology, Delhi at the request of the Board of Consultants, Kosi Project. The objective of this study was to determine the rise and fall of the river bed elevation prior to and after the construction of Kosi Project.

The total length from Chatra to Koparia was divided into six reaches (Table-2) (Singh and Chandra, 1975).

Table – 2

Extent of various Reaches for the Evaluation of Effect of Embankment on the River Bed

Sl.No.	Reach	Place	
		From	To
1.	I	Chatra	Jalpapur
2.	II	Jalpapur	Bhimnagar
3.	III	Bhimnagar	Dagmara
4.	IV	Dagmara	Saupaul
5.	V	Saupaul	Mahesi
6.	VI	Mahesi	Koparia

The data of 98 cross sections of the river for the year 1955 to 1974 were supplied by Project authorities. The standard width of each section and inter-distance between sections was also supplied. Reduced levels in the cross-sections were shown at 150 m intervals. Where the bed elevations of the river, changed considerably, the reduced levels were given at 30 m intervals. In some of the cross-sections the data were taken at irregular intervals. The yearly peak-discharge, the annual runoff of the river and suspended silt data were also made available.

The results for each reach are given below :

Reach I : During the pre-barrage period, this reach had a tendency to scour at a rate of 1.76 cm/year. In the post-barrage period, this reach shows silting at the rate of 12.34 cm/year, i.e. from scouring it has changed to silting after the construction of the barrage.

Reach II : In the pre-barrage period, this reach was scouring at a high rate of 16.56 cm/year but after the barrage it has been rising at a rate of 10.7 cm/year. Thus, from a 'Dredging' reach it has become an 'Aggrading' reach after the construction of the barrage.

Reach III : This reach is just downstream of the barrage at Bhimnagar and scouring in this reach has been reduced from 3.56 cm to 0.83 cm/year after the construction of the barrage.

Reach IV : The scouring rate was negligible during the pre-barrage period (0.37 cm/year) but in the post-barrage period, this showing a slight rise of 1.86 cm/year.

Reach V: This reach was silting at a rate of 9.56 cm/year but after the construction of the barrage the silting rate has been reduced to 6.36 cm/year.

each VI : The data for the pre-barrage period is not available but in the post-barrage period this reach is silting at a high rate of 12.03 cm/year.

A brief summary of the results regarding change in bed level and volume change in river bed has been given in Table-3.

Table –3

Change in River Bed Level during Pre and Post Barrage Period

Reach	Change in river bed levels (cm/year) (1963-74)			
	Pre-Barrage		Post Barrage	
	Rise	Fall	Rise	Fall
I	-	1.76	12.34	-
II	-	16.56	10.70	-
III	-	3.56	-	0.83
IV	-	0.38	1.86	-
V	9.56	-	6.35	-
VI	-	-	12.03	-

Apart from the main river, siltation was also a serious problem in Kosi canal system. In the year 1967-68 the average sedimentation in the main canals raised from 0.6 m to 1.8 m. In the branch canals the siltation raised bed from 0.38 m to 1.07 m.

7.3.3 Study about the shifting process of river

After the construction of the barrage and flood embankments on Kosi were completed, the Govt. of Bihar appointed a Technical Committee in the year 1971.

One of the terms of reference of the Committee was to review the functioning of the existing barrage and to suggest further measures that may be necessary to ensure optimum flood protection in the Kosi basin. While analyzing the effect of the Bhimnagar barrage and flood embankment on the Kosi river regime, the Committee had outlined the causes of shifting courses of Kosi river. The conclusion by the Committee are noted below :

- Siltation to the extent of about 3.4 to 4.72 ft. (1.04 m to 1.44 m) is found to have occurred in the pond immediately upstream of the barrage. (Further upstream also siltation has occurred to a lesser extent all along the river up to about Chatra which obviously is due to general aggrading tendency of the river).

- Cubature studies should be periodically made to ascertain the extent of siltation in future. In addition, gauge should be observed regularly at selected stations along both the afflux bunds and specific gauge discharge curves prepared to obtain additional evidence in respect of changes in the river bed levels.

- Close vigilance and timely action are warranted for the safety to the afflux bunds, guide bunds and approach bunds in view of the progressive tendency of aggradation of the river bed levels.

- Sediment entry into the Kosi canals is augmented by the rising trend of river bed levels in the pond. It is, therefore, necessary to maintain lower bed levels by adopting possible remedial measures. One such measure is to effect periodical flushing operations which would help rapid and more effective flushing. Extreme care will have to be taken to ensure safety of the guide bunds, afflux bunds and approach bunds when high velocities are generated along their faces during flushing. Care also needs to be exercised for ensuring safety of bunds against piping.

- Another measure likely to be effective for maintaining lower bed levels in the pond upstream of barrage is by running non-excluder bays in the pocket. Model experiments are proposed to be conducted for studying this aspect further" (G.O.I., 1973)

8.0 RASHTRIYA BARH AYOG RECOMMENDATIONS

The Rashtriya Barh Ayog (National Commission on Floods) consider that channel improvement as a method of flood stage reduction is economically practicable only on channels of small streams carrying a manageable high flood discharge. In the case of larger rivers, such a method is generally impracticable on account of the huge capital and maintenance costs for dredging and the impracticability of disposing of the excavated material over developed areas. This method may be useful where construction or improvement of embankments is extremely expensive or where local channel improvements can reduce water levels for a long distance upstream (RBA p. 87, 1980)

In the initial policy statement regarding floods in India as placed before the Parliament on 3rd October, 1954, channel improvements were suggested as a short term measure.

Ministers' Committee on Flood and Flood Relief 1972 recommended investigation of the possibility of river diversion and channel improvement as a measure of flood control.

CHAPTER - IV

PROCESS OF SEDIMENTATION AND SILTATION

1.0 INTRODUCTION:

The Himalayan Rivers carry heavy load of silt from the steep valleys. These rivers enter the Bay of Bengal through deltaic region where they unload the silt resulting in building up delta over the years.

All the sediments that are transported by various rivers debouching from Himalayas are found to have resulted by the process of weathering of sedimentary rocks. The size, the mineral composition, the density and other factors such as surface texture etc depend on the nature of parent rock from which the sediment is formed. The rock forms in the Himalayan region are sedimentary type, which weather easily due to the action of snow melting and wind abrasion. Due to the hard nature of the rocks, the catchments of Central and South Indian rivers are more resistant to erosion whereas the catchments of Himalayan Rivers produce a large amount of silt.

The study of sediment transport by water is of importance in several aspects of hydraulic engineering;

- Fluvial Hydraulics	: Knowledge of sediment transport forms the basis for the design of river training works, navigational improvement, flood control.
- Irrigation	: Design of stable channel, intakes, settling basins.
- Coastal Engineering	: Protection of littoral drifts, design of coastal protection works and harbours.
- Dredging	: The suction, transport and deposition of materials has many aspects related to sediment.

The main objectives of sediment transport hydraulics is to predict whether an equilibrium condition, erosion (scour) or deposition (silting) will occur and to determine the quantities involved. The rate of sediment transport, expressed as mass, weight, or volume per unit time can be determined from the measurements or from the calculations. Both methods only have a low degree of accuracy so that the sensitivity of the design to possible variation in the calculated transport rates has to be considered.

The main reason for the empirical character of sediment transport knowledge is the complex in the transport process. There are several equation for estimation of sediment discharge. Research workers in this field are coming up with different equations on the basis of additional data available or existing analysis with new methods/technology subsequently developed. Several investigators have tested the formulae for assessing their adequacy/accuracy. Computed values however not only differ from one equation to another considerably but also are found to be deviate significantly from the measured values except for a very few cases. These tests results clearly demonstrate how difficult is the task to predict sediment discharge in the rivers.

For understanding of the sediment transport mechanism, it is necessary to study the properties of sediment/ water and characteristics of the flow. The size, shape and the specific gravity are some of the relevant basic properties of sediment which are commonly used in the study of sediment transport. From these properties important parameters for sediment transport such as fall velocity, critical tractive force or critical velocity are estimated/worked out. In doing so the shape of gradation curve of the sediment is also required to be taken into consideration as the behaviour of a single grain or grains of uniform size and the mixtures having small and large grains is different.

2.0 PROPERTIES OF THE TRANSPORT MATERIAL

Some of the properties of sediment which are often used are:

- Size
- Shape
- Density
- Specific Gravity
- Fall velocity
- Porosity

From the above basic properties, fall velocity/critical velocity or critical tractive force are worked out taking into account the properties of water and characteristics of flow.

2.1 Fall Velocity

The fall velocity of a sediment is an important parameter in studies on suspension and sedimentation of sediments.

Fall velocity also depends upon the turbulence in the flow apart from turbulence caused by settlement of particles. However, oscillating fluid is under the influence of turbulent flow. The turbulence may be defined as a three dimensional random phenomena and as such some of the particles caught in rising component of the turbulence may settle slowly. Therefore overall effects of the turbulence on the settling velocity of the particles may not be very significant.

3.0 MODES OF TRANSPORT

With very low flow there is no movement of sediment particle on the bed. As the critical condition for initiation of the motion is reached, particle begins to move. This initial movement is in the form of sliding/rolling on the bed. With further increase in the flow the forces on the particle increase. As a result, particle lifted from the bed may travel in suspension very near to the bed in a short length like a hopping motion. This is known as saltation stage. With further increase in flow velocity, jumps executed by grains would become more frequent and longer and some of the particles may be swept in the main body of the flow by upward component of turbulence and kept in suspension for the longer time. The sediment carried in suspension in this manner is known as suspended sediment load. The concentration of suspended sediment on a vertical varies depending upon the fall velocity of the particle and the shear velocity of the flow.

4.0 TRANSPORT MECHANISM

According to the mechanism of transport two major modes may be distinguished :

1. Bed load	-	movement of particles in contact with the bed by rolling, sliding and jumping
2. Suspended load	-	movement of particles in the flow. The settling tendency of the particle is continuously compensated by the diffusive, action of the turbulent flow field.

A sharp distinction is not possible. A general criterion for the beginning of suspended load is a ratio of shear velocity and fall velocity ($U^*/W \sim 1.5$). Sometimes also siltation load is mentioned. This is the mode where particles bounce from one position to another. This is only important for particle movement in air. The maximum particle elevation of a particle moving in water is in the order of 2-3 times the diameter so that this mode of transport can be considered as bed load.

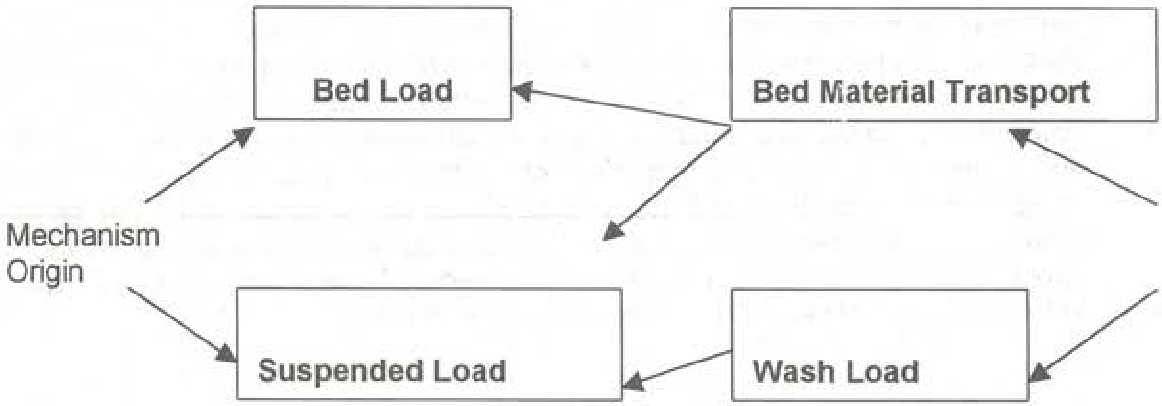
According to the origin of the transported material a distinction is made as follows:

4.1 Bed material transport

This transport has its origin in the bed, which means that the transport is determined by the bed and flow conditions (can consist of bed load and suspended load).

4.2 Wash load

Transport of particles not or in small quantities in the bed. The material is supplied by external sources (erosion) and no direct relationship with the local conditions exists (can only be transported as suspended load, generally fine material < 50)[2]. It can have influence on turbulence and viscosity and therefore have some influence on the flow.



wash load is not important for changes in the bed of a river but only for sedimentation in reservoir etc.

5.0 CLASSIFICATION OF SEDIMENT

Sediment can be classified under the following categories.

- Bed sediment load
- Wash load

Bed sediment is that part of sediment having particle sizes found in appreciable quantities in the shifting portions of the bed. Wash load is that part of sediment particles having found in very small quantities in the shifting portion of the bed. Bed sediment load includes bed load as well as suspended load. Transport of the bed sediment load depends upon the transporting capacity of the stream whereas the transport of the wash load depends upon the availability of the material from the catchment. It may remain in suspension and may not settle on the stream bed. In most of the sediment discharge formulae only bed sediment load is taken into consideration.

6.0 SILTATION PROCESSES

A two pronged attacks have been visualized regarding Siltation process and to reduce the Siltation process through catchment treatment. In the upstream reaches, the rivers have steep slopes and high sediment transport capacity. The slopes go on reducing along the travel of the rivers until the river meet the sea. The sediment transporting capacity also reduces along its path in the downstream direction resulting in sedimentation in the bed and banks. Thus the tendency of sedimentation in the alluvial planes or in the lower reaches can only be controlled and resisted.

The natural phenomenon of soil erosion is in the form of silt load in a river The soil that is eroded finds its way in the flowing water of a river. River cross section is subjected to erosion and siltation by flowing fluid depending upon hydraulic and hydrologic characteristics covered under silt transport theory. Construction of dam reduces the velocity of water in upstream thereby causing siltation in the reservoir. The silt free water released through spillway, causes erosion downstream of the spillway along its length. Siltation an be broadly divided into two parts viz. (i) Reservoir Siltation and (ii) River bed Siltation

Reservoir Siltation is a natural process due to construction of dam etc. However, river bed sedimentation is not clearly visible as it is slow processing and not monitored regularly. Natural disasters such as earth quakes, land slides do accelerate river Siltation appreciably resulting change in morphology of the river.

Treatment of the catchment of such rivers would be re-forestation, construction of check dams, contour bunding, etc. Projects in this direction are being taken up by many states for their own benefits.

As far as the overall morphology of rivers is concerned, the sea level can be treated as constant. The entire sediment load is dropped in the vicinity of the river mouth and the sea bed is subjected to continuous rise. This rise is the main cause for the constant shifting of channel and formation of Delta in rivers. The tidal range of river Ganga in the deltaic region is of the order of 5 m. Therefore, dredging in the deltaic region may not serve many useful purposes to improve the hydraulic gradient at the mouth. Another factor which tends to close the river mouth in the deltaic region is the littoral drift which is movement of sediment parallel to the shore, due to wave action. Considering the vast area involved and non-availability of suitable disposal grounds in the vicinity, dredging the river mouth does not appear to be a viable solution.

6.1 Silt Load in Indian Rivers

Central Water Commission has recently conducted a study to find out the silt load i.e. quantity of silt carried by river water to sea. Silt data for last 10 years for all the major rivers were considered to work out average annual sediment load of each basin in the country. It was found that on an average 1066 million tons of sediment is carried to the sea every year by our river systems.

6.2 Assessment of Siltation

There are several methods which could be employed to assess siltation in a river bed. Silt content is worked out on the basis of silt data that are collected at discharge observation sites. Aggradation/degradation is assessed by cubature method or specific discharge gauge curve as explained below.

6.2.1 Cubature Method

This is positive and direct method of finding out aggradation/degradation in a river reach. Study is carried out for a specific reach of a river and for specific period. The cubic contents of deposition are worked out. Positive deposition indicates aggradation whereas negative value indicates degradation.

6.2.2 Specific Discharge-Gauge Curve

This is indirect method of assessing aggradation. The rise of water level for the same discharge in the period under consideration indicates aggradation at the specific location e.g. for the same flood discharge, the water stage of Yellow river in 1985 was higher by about 1.0 to 1.8 metre than the water stage of 1958 of the river.

6.2.3 Embankment and Aggradation

Embankment is a method of flood control which has been adopted universally by all flood affected countries. Prior to 1954, there was a few flood embankment in the country mainly constructed and maintained by local people or individuals. These embankments known as Zamindari Embankments were not properly designed and constructed. Nevertheless, they continued to exist even after 1954 when India began to take protection measures to control flood. Flood embankments were constructed in late fifties and sixties. Till date embankments have been constructed along almost all the rivers. Embankments were initially constructed with a view to affording prompt and immediate relief to flood affected people. Other measures were expected to follow towards finding permanent solution. Embankments along Kosi were completed in 1963 with the hope that in due course of time, the dams in the hilly region in Nepal would come up. Likewise, dams were expected in Brahmaputra basin. Construction of dams across a river does not control flood water alone but also it controls silt load which is the chief cause of river shifting tendency. In D.V.C. Project, the construction of dams has reduced the flood menace in Damodar river considerably.

The natural river course would drop extra silt on flood plain as a result of reduced velocity of flood water. Thus silt would be spread on flood plain which would act as natural manure. Embankment construction entails cutting the flood plain area which hitherto was the playground for the swollen river. Confining river course between embankments prevents silt from spreading on total flood plain area thereby making silt to cause aggradation/degradation or river bed. It does not imply that aggradation occurs in embanked rivers only. Even otherwise aggradation takes place. The process is somewhat accelerated when river is embanked from both sides.

CHAPTER - V

GEOLOGICAL FACTORS IN SILTATION

1.0 INTRODUCTION

There are about 120 major and medium rivers in India that are grouped under six major river systems of the country. The number of minor or small rivers that flow through the country is legion. Heavy rainfall has been the main cause of floods in India for any river basin. Besides meteorological situations, there are some manmade factors that are also responsible for causing serious floods in different parts of the country. The problem of flooding is closely related with the siltation. Various domains of different energy conditions develop in a river system resulting in erosion at certain locations and deposition at others. The problem of erosion is prevalent in the initial reaches of the river in which the energy in the system is high due to steeper bed gradient. The problem becomes more acute during floods when the energy of the system increases in a short span of time. The problem of siltation is more acute in lower reaches of a river system in general where the energy in the system is low and the flowing water drops sediment load. The problem of siltation has been observed to be more acute when floods recede and energy level in the system drops suddenly. Similarly, the problem of siltation becomes more serious in the last stages of a river system i.e. near the estuaries where the energy level drops suddenly. The man made structures like flood protection works are also responsible for development of siltation problem at certain sites as these affect the energy conditions locally and cause drainage congestion. Besides hydrological, meteorological, anthropogenic activities the physiographic, geomorphological, geological, and tectonic set-up of area in which these basins/river systems are located have a major and often overriding influence on the quantity of siltation.

2.0 PHYSIOGRAPHY AND DRAINAGE

Physiographically, the country can be divided into three well defined regions each having distinguishing characters of its own. The first is Peninsular Shield lying to the south of the plains of Indo Gangetic-Brahmaputra river system. The second division comprises the Indo Gangetic-Brahmaputra plains that stretch across north India from Assam and West Bengal in the east to Punjab and Sind on the west. The third and most important division is Extra-Peninsula, the mountainous region formed of mighty Himalayan ranges and their extensions into Baluchistan on one hand and Burma and Arakan on the other. These three divisions exhibit marked contrast in physical features, geomorphology, geology and control the hydraulics and nature of rivers which either originate or pass through them.

Physiographically, the Peninsula is an ancient plateau exposed to denudation for over a large period of time and approaching peneplanation. Its mountains are of relict type or remnants of mountains that existed in the past. Its rivers have, for the most part, a comparatively flat country with low gradients to traverse. These rivers have carved shallow and broad valleys. Stratigraphically, Peninsula is a shield area composed of geologically ancient rocks of diverse origin, most of which have undergone metamorphism. Structurally, the Peninsula represents a stable block of earth's crust that has remained unaffected by tectonic and oregnic movements practically since the close of Pre-Cambrian era. The later changes that it suffered have been mainly of the nature of normal and block faulting because of which some parts have sunk down as compared to others.

Major mountain ranges of Peninsular India are the Western Ghats, Eastern Ghats, Vindhyans, Satpuras, the Aravallis and those forming the Meghalaya Plateau and Mikir Hills. The Western Ghats represent a well marked feature along the western coast of India from Tapi Valley down to Cape Comorin. These are nearly 1,600 km long and their average elevation varies from 1100 m to 1200 m but many peaks rise to over 2400 m. The rivers like Godavari, Bhima and Krishna rise in Western Ghats in Maharashtra region. Western Ghats are generally known as Sahyadris. Further south, in Karnataka, the Ghats tend to recede 50-65 km from coast. In the Nilgiris, the Eastern Ghats join them to form a mountain knot. To the south of Nilgiris there is a gap in the Western Ghats known as Palghat Gap which has maximum width of 25 km. south of Palghat Gap these rise again and further south they decrease in height and disappear finally a few miles north of Cape Comorin. Though situated very close to the Arabian Sea, the Western Ghats form the real watershed of Peninsula, they are exposed to full vehemence of the SW monsoon and receive around 3700 mm of rain per annum. All important peninsular rivers viz. Godavari, Krishna, Cauvery rise in Western Ghats and flow eastward into the Bay of Bengal.

Eastern Ghats are a series of rather detached hills of heterogeneous composition that stretch intermittently from the northern border of Orissa through the coastal regions of Andhra Pradesh down to the valley of Krishna river. Their average elevation is about 800 m. south of Krishna valley, they continue into Kondavidu hills.

The Vindhyan Mountains are fairly continuous group of hill ranges or rather a series of plateaus lying to the north of Narmada river and extending from Sasaram (24° 5 7' N: 84° E) in Bihar to Jobat (22° 27' N: 74° 35'E) in Gujarat. The general elevation is 450 to 600 m. Together with Satpuras, the Vindhya Mountains form the watershed of Central India from which rise Narmada, Chambal, Betwa, Tons, Ken, Sone and many other rivers. Some of these flow into the Ganges and others into Godavari and Mahanadi except Narmada which flows into the Arabian Sea.

The Satpura Mountains separate Narmada and Tapi rivers. They have ENE-WSW trend and extend from Ranchi-Hazaribagh in the east to Rajpipla Hills in Gujarat. In Madhya Pradesh these occupy a 120-160 km wide zone.

Raj Mahal Hills located at the head of Ganges delta are confined between latitudes 24° 30' and 25° 15' roughly along 87° 30' longitude. Aravalli Mountains are now the remnants of once great mountain ranges of tectonic origin. They cross Rajasthan from SW to NE dividing the arid semi-arid desert of Bikaner, Jodhpur and Jaisalmer area on the west from more fertile region of Udaipur and Jaipur in the east. The small detached quartzite ridges near Delhi are their northern most stumps. They gradually rise higher towards the SW. From Beawer onwards they form conspicuous ridges and beyond Merwara they spread out into a zone of hills that is 40-50 km. wide. Though Aravallis terminate in Gujarat in SW and near Delhi in NE, there are indications that they extend in both directions. The Aravallis are thought to constitute one of the finest examples of a true tectonic range. They form the major watershed of north India separating the drainage of Ganga river system from that of Indus that debouch into the Bay of Bengal and the Arabian sea respectively.

There are numerous rivers traversing Indian Peninsula that include Damodar, Subarnarekha, Brahmani, Mahanadi, Godavari, Krishna, Pamer, Cauvery and Tambraparni flow into the Bay of Bengal while Narmada and Tapi flow into the Arabian Sea. The Banas, Luni, Chambal, Sind, Betwa, Southern Tons, Ken and Sone are peninsular rivers of North India that belong to Ganges System while there are also a few others which rise in Central India and the Aravallis and flow into Rann of Kutch or Gulf of Cambay. Most of peninsular rivers can be said to have reached a mature state of development and have very little bed gradient and almost nil down cutting power hence bank erosion is common during floods. Those carry suspended load and no bed load due to low energy regimes, particularly in down stream reaches. The larger rivers like Mahanadi, Krishna, Godavari , Cauvery have built up deltas at their mouths where they deposit their bed load due to drastic reduction in energy on meeting the sea. The delta formation is hampered in case of smaller rivers due to presence of strong currents in ocean and these take away the sediments dropped due to sudden loss of energy. In Western Ghats, the rivers still show an early stage of development probably because there may have been an upward tilt and uplift of western Ghats in Tertiary era. Also the gradient of rivers is steeper because these run for much shorter distances before debouching into sea. The Narmada and Tapti are the only large rivers to flow westward and their courses are determined by a rift or fault zone and contain a large thickness of Pleistocene and Recent Alluvium.

There are numerous waterfalls in Western Ghats that are generally found along the courses of west flowing rivers. Some of them like Jog Falls and Sivasamundram along the Cauvery are very big waterfalls. There are several falls and cascades along Tons, Chambal, Sone, Betwa. Similarly Dhuandhar falls in Marble Rocks near Jabalpur are well known geomorphic features.

The Extra-Peninsula has mountains surrounding India on the north and northwest and northeast. The tectonic ranges resulted from collision of Indian Plate with northern Eurasian Plate. Of these, Himalayas and Burmese arc are of importance in the context of Indian rivers. The Himalayas extend with a smooth sweep from Arunachal Pradesh to Kashmir for a length of about 2,500 km. The Himalayas in western sector are followed by Karakoram Range in north and Tibet Plateau along rest of portion. Important mountain ranges in and in vicinity of Himalayas are Tibet Plateau, Karakoram, Kailash and Ladakh Ranges, Zanskar Range and Pirpanjal Range. Himalayas, based on physiographical, geomorphological and tectonics have been divided into Inner Himalayas or Central Himalayas, Lesser Himalayas and Foot Hills or Outer Himalayas or Frontal Fold belt. The Foot Hills zone is 8 to 50 km wide and altitude rarely exceeds 1500 m. The hills are covered with dense forest and rainfall varies between 1000 mm and 2500 mm.

The Lesser Himalayan zone is 60-80 km wide and has average altitude of about 3000 m. Vegetation varies with altitude from evergreen oak forests between 1500 and 2000 m to coniferous forests between 2500 m and 3000 m altitude. The Great Himalayas or Central Himalayas comprising zone of snowcapped peaks consists of lower Alpine Zone up to 4800 m elevation and upper and snow bound zone between 4500 m and 5100 m elevation. The Trans-Himalayan zone is about 40 km wide and contains valleys of the rivers rising beyond the Great Himalayas at an altitude between 3,600 m and 4200 m. The snow line or the lowest limit of perpetual snow and ice is at different altitudes in different parts of Himalayas and its neighbouring ranges. In eastern sector in Arunachal Himalayas the snow line is at 4350 m or above whereas in Kashmir Himalayas it varies between 5100 m and 5100 m altitude. This could be due to scarcity of moisture in the region of Western Himalayas. The glaciers also descend to lower levels in western Himalayas as compared to those in Eastern Himalayas. The glaciers are now confined to the higher ranges. The important glaciers are valley glaciers flowing through longitudinal valleys and have large dimensions. The hanging glaciers along short transverse valleys are less important and are more vulnerable to variation in temperature. Many of the Himalayan glaciers are much smaller than those located in Karakoram and these are receding gradually. The Himalayan rivers are to a large extent fed by glaciers. The larger snow fed streams are often full in summers because of more melting of snow/ice in glaciers. Rains in Sub-Himalayas also contribute to the waters of these rivers.

The present glaciers are remnants of the extensive glaciation of Pleistocene period when very large areas of mountainous tract were covered by ice and snow. Terminal moraines are found at as low altitudes as 1500 m in the region of Lesser Himalayas. There are other glacial features such as fluvio-glacial deposits and moraine filled glacial lakes suggest at the Pleistocene glaciation covered very large areas in the Himalayas and extended down to very low altitudes. Between Kashmir in the NW and Arunachal Pradesh in the east, the Himalayas give rise to some 20 important rivers. They rise from Great Himalayas, Karakoram, Ladakh, Zanskar, Kailash and Trans-Himalayan ranges and ultimately join together to form the three great systems of Indus, Ganges and Brahmaputra after cutting through the mountains. The head streams are generally fed from mountain glaciers. It is remarkable that though the Indus, Satluj and Tsangpo rise in the neighbourhood of Mount Kailash, they flow in different directions to reach the plains.

The river Indus of Indus System, westernmost of Himalayan river systems is one of the mightiest rivers of the world draining glaciers and slopes of many peaks and receiving many great rivers as its tributaries. It has total length of about 290 km. It flows for about 290 km over a flat country along the inner flank of Ladakh range before cutting across the range. Chief tributaries of Indus are Zanskar, Dras, Shyok, Shigar and Gilgit in this area. Other tributaries in lower reaches are Jhelum, Chenab, Ravi, Satluj and Beas.

The drainage basin of Ganges covers one of the most thickly populated regions of the world. The Ganges System includes many important rivers like Yamuna, Kali, Karnali, Ramganga, Gandak and Kosi. All these rise in Himalayas and are snow fed. The peninsular tributaries include Chambal, Betwa, Tons, Ken, Sone etc. which rise from highlands of Central India. The delta of Ganges begins near Gaur. The present main branch of the river flows in southeasterly direction and is known as Padma in Bangladesh. In recent past the main channel of Ganges in Bengal was Hooghly together with its feeders.

The Brahmaputra System has Brahmaputra as main river that is known as Tsangpo in Tibet has source at Tanchok Khambab Chorten (31°31'N: 82°00'E) in Chema yung dung Glacier. It has a long course through the comparatively dry and flat region of southern Tibet before it crosses Himalayas near Namcha Barwa. Its chief tributaries in India are Amuchu, Raidak, Sankosh, Manas, Bhareli, Subansiri, Dibang and Lohit. Total length from its source in SW Tibet to its mouth in the Bay of Bengal is about 2900 km. It is known as Dihang or Siang in Arunachal before it debouches into planes near Pasighat. The course of Tsangpo in Tibet is through plains that have not been deeply cut and it is quiet sluggish river there. The elevation of its bed is 4490 m near Trandom, 3590 m near Shingtse, 2425 m at Gyela Sindong near Namcha Barwa and only 130 m near Sadiya in Assam where it enters plains. Chief westerly flowing tributaries of Tsangpo are Khi (Lhasa) river, Nyang, Raang and Shang, Tsangpo flows for nearly 1600 km in Tibet before it takes a knee bend encircling Namcha Barwa before breaking through Himalayas. During its course through Himalayas, the river (known as Dihang) descends through 2250 m, as altitude of Sadiya is only 130 m above MSL. The Brahmaputra in plains is a mighty river and spreads into vast expanse of water when it floods, it brings down enormous quantities of sediments. There are several islands in its course that it changes often. In Bangladesh it is known locally as Jamuna up to its confluence with Padma.

Most of the Himalayan rivers rise in Great Himalayas or Trans-Himalayas. The fact that the chief watershed is beyond the line of great peaks is generally cited as evidence in favour of the drainage being antecedent or having been in existence before rising of the Himalayas. The courses of rivers, where they cross the high range are at right angles to latter. There are several cases of recession of head of streams in hills by the action of streams as well as glaciers that feed them. The head erosion has, in some cases, led to the source going to the northern slopes of Great Himalayas and capturing the drainage of other streams. Rivers have also inherited the valleys of glaciers in many cases; the tributary streams are seen hanging many meters above main streams, the confluence being marked by cascades or waterfalls. The Himalayan rivers like Indus, Ganges and Brahmaputra have changed their courses in plains frequently in historic times. Compared to this, the changes in courses of Peninsular rivers are not so marked.

Peninsular rivers are entirely rain fed so that these have maximum discharge only during and after southwest monsoon i.e. from June to October. They are fairly active in their upper reaches where they generally flow over rocky bed and actively erode the bed. They have built deltas near their mouths where they deposit their load of silt carried from higher reaches in the form of suspended load. The delta regions or lower reaches are frequently liable to floods where the distributaries are silted up due to dropping of suspended load by rivers in view of reduction in energy of system. The distributaries here are not open enough for carrying away the surplus water as these are silted up. The deltas of Godavari, Krishna, Mahanadi and Cauvery are examples of this.

Compared to the Peninsular rivers, the Himalayan river systems are mighty giants. The Indus carries to sea an average of a million tons of silt per day, Ganges little less and Brahmaputra a little more. The Himalayan rivers are fed both by rain and snow. In their courses through mountains, they have steeper bed gradient and carry much coarse materials including pebbles and boulders brought in by glaciers and also torn off from bed and banks. These are carried as bed load and deposited as soon as those rivers enter the plains. This is evident from the presence of enormous debris fans at debouching points of these rivers in plains. They carry enormous quantities of fine sand and silt derived from Himalayas, higher Peninsula uplands and Indo Gangetic Plains during high floods. The aggrading action of these rivers is confined to lower reaches in general in IndoGangetic-Brahmaputra Plains and in deltaic reaches. However, same can be observed in certain stretches in higher reaches when rivers locally flow in low energy regimes such as Indus in Ladakh and Jhelum in Kashmir Valley.

All the major rivers of India are liable to floods, especially in middle or lower reaches in general. Floods in plains are due to high precipitation of rain during short periods when river channels are unable to carry the run off and river banks are overtopped. The problem becomes more acute when the river channels are already silted up and intensity of siltation increases when more silt is deposited by receding floodwater. In case of Himalayan rivers the floods in upper reaches are caused due to formation of barriers along the courses of rivers due to landslides, accumulation of vegetation or glacial moraines. Sometimes the floods are also caused due to obstruction of river courses by landslides during earthquakes. Floods are also brought about by exceptionally heavy rainfall during a short period. With the steady deforestation of the country, the soil cover is stripped off by erosion, percolation diminishes and erosion intensifies. The soil transported from here is deposited in lower reaches causing this problem of siltation.

3.0 GEOLOGY

India has been divided both geologically and geographically into three distinct units.

i. Montane Zone of Extra Peninsular Region.
ii. Indo-Ganga Alluvial Plain
iii. Peninsular Region.

The mountains in the Extra-Peninsular Region have mostly highly disturbed strata as a result of repeated tectonic movements. The rocks of Lesser Himalayas with their thick sequence of sediments, probably include the member or the equivalents of Peninsular Formation. The buckled fringe of the Peninsula extends up to southern flank of the Great Himalaya (Fig.- 1).

The Indo-Ganga alluvium occupies the depressed zone between the mountainous region of the north and the Peninsular region of the south covering an area of 775,000 sq. km. This depression is considered to be an orogenic zone of down warps which is in continuity with the earlier Siwalik orogenic trough of Miocene to early Pleistocene age. Geophysical investigations have revealed that the thickness of the alluvium in Bihar is approximately 1830 m and drilling done near Calcutta has established its thickness in that area to be 2000 m. Since very early age in the geological history of the country, the Peninsular India has been considered a stable landmass which is mostly composed of rocks belonging to Pre- Cambrian age. On these folded strata there had been very little effect of the lateral thrusts and mountain building forces which disturbed the Extra-Peninsular region in post-Cambrian ages.

The ancient granite gneisses comprising ortho and paragneisses, injection gneisses and schists are grouped together to represent Archean rocks. This group probably includes a portion of Basement Complex and in many cases, the age relationship between this and the rocks grouped under and Lower Proterozoic is not quite discernible. These include Charnockite, Khondalite, Peninsular Granites with younger phases and magmatite complex of South India, Bababudan Group of Dharwar Super Group, Eastern Green stone etc. A group of both sedimentary and igneous rocks which are highly metamorphosed, folded and occur within Archeans have been assigned Proterozoic age. These have been divided in to Lower Proterozoic, Middle Proterozoic and Upper Proterozoic and some rocks have been left as unclassified. Proterozoic like Mahakoshal Group, Sakoli Group of Central India, Bonai Group of East India and Chitradurga and unclassified Dharwar rocks belonging to oldest Proterozoic which is called Archean_Proterozoic: Sausar Group of Central India and Aravalli Group of Western India have been assigned Lower Proterozoic age whereas Delhi Super

Group of Western India, Gwalior, Bijawar, Khairagarh, Abujmar, Chilpi Groups of Central India and Kolhan Group of E India have been assigned transitional age between Lower and Middle Proterozoic. Chotanagpur Gneissic Complex of Eastern India, Gneissic Complex of Meghalaya in Peninsular shield and Jutogh Group, Almora Crystallines, Central Crystallines and equivalents in Western Himalaya; Kunchanjengha Gneiss, Darjeeling Gneiss and Paro gneiss of E Himalaya; Sela Group and equivalent formations, Tidding Group of NE Himalaya and Naga metamorphites of NE India have been grouped in undifferentiated Proterozoic and Archean-Proterozoic. The Middle Proterozoic includes Kaimur and Semri Group of Vndhyan Super Group; Cuddapah Super Group and its equivalents of South India, Munger Group of E India; Shillong Group of Meghalaya; Sirban Limestone, Shali Group, Sundernagar Formation, Mandi-Darla Volcanics, Rampur Group, Deoban Group and Garhwal Group of Western Himalayas; Chattisgarh and Indravati Groups of Central India; Salkhala and Buniyar Group of Western Himalayas; Daling Group and Tenga and Potin Formations and equivalent in Eastern Himalayas have been assigned transitional age between Middle and Upper Proterozoic. The Proterozoic III or Upper Proterozoic includes Marwar Super Group of Rajasthan; Bhander and Rewa Groups of Vindhyan Super Group; Kurnool and Bhima Groups and equivalents of Southern and Central India; Gamir-Baila Formations, Simla Group, Jaunsar Group and equivalents in Western Himalaya. The rocks of undifferentiated Blaini, Infra-Karol, Karol and Tal Formations, Katarigali, Manjir, Machhal, Lolab and Karihul Formations, Martoli-Ralam, Batal-Kunzam La and equivalents of Western Himalaya and Everest Pelites of Eastern Himalaya have been assigned Proterozoic III- Cambrian age. Ordvician to Carboniferous age has been assigned to un-differentiated Garbhyang, Shiala, Thango and Thakche Formations, Lipak and Po Formation, Fenestella shale, Syringothyris Limestone and equivalent Formations in Western Himalayas. The undifferentiated Lach, Bichom, Bhareli Formations of NE Himalaya, Carboniferous Formations of Ladakh-Karakoram and Permain Formation Western India; Ranjit Pebble Slate and associated Formations of Eastern Himalaya have been assigned Carboniferous- Permian Age. The rooks ranging in age from Permian to Jurassic include undifferentiated Zewan Formation, Nishat Bagh Plant Beds, Productus Shales, Lilang and Vihi Groups, Kuling Formation, Guriyal and Mandi Formations of Western Himalaya; undifferentiated Carboniferous to Jurassic formations of Jammu; Permain-Triassic and Carboniferous –Triassic Formations of Ladakh-Korakoram. Undifferentiated Gondwana SuperGroup has been assigned Upper Carboniferous to Lower Triassic age. The Jurassic rocks include Baisakhi, Jaiselmer, Lathi, Bedesar and equivalent formations of Western India. These are succeeded by Jurassic-Cretaceous rocks belonging to Pariwar and Himmat Nagar Formations of Western India; undifferentiated Spiti, Wumuch, Chikim and Guimal Formations of Western Himalayas and equivalent formation in Ladakh and Karakoram. The rocks belonging to Cretaceous age include Abur, Fategarh, Bhuj formations and equivalent in Western India; Lameta and Bagh Groups of Western and Central India; Khasi Group of Meghalaya; Cretaceous Formation of Tiruchirapalli and those of Ladakh-Karakoram. The Indus Group and Cretaceous to Palaeogene formations of Ladakh-Karakoram have been assigned Cretaceous-Tertiary age. Palana and Madh Formations of W India; Niniyur

Formation of South India are included in Palaeocene age group. The Subathu Formation and equivalents of Western Himalaya and Mithakari Group of Andaman-Nicobar Islands belong to Palaeocene-Eocene ages. The rocks grouped under Eocene include Kanji Group of W Himalaya, Yingkiong Formation of NE Himalaya; Disang and Jaintia Groups of NE India and Eocene Formations of Western India. Barail Group of NE India has been assigned Eocene-Oligocene age whereas Andman Flysch and Oligocene Formation of Gujrat have been kept in Oligocene age. The Oligocene-Miocene rocks include those belonging to Kasauli, Dagshai, Dharamsala and Murree formations of Western Himalayas. Surma Group and Baghmara Formation of NE India; Baripada Formation of Eastern India; Khari and Gaj Formations of Western India and Cudalore Formation of South India have been assigned Miocene age. These are succeeded by the rocks belonging to Tipam Group of NE India; Rajamahendry, Warkhali and Quilon Formations of South India; Chengapara Formation of Meghalaya and Archipelago Group of Andaman-Nicobar Islands which have been assigned Mio-Pliocene age. The Kankawati Formation and Dwarka Beds of Western India and Upper Tertiary beds of East India are of Pliocene age. Neogene-Pleistocene include undifferentiated Siwalik Group of rocks of Himalayas and Plio-Pleistocene rocks includes those belonging to Karewa Group of Western Himalayas and Dhupitila and Dihing Formation of NE India. Undifferentiated Quaternary sediments and Miliolite Limestone have been grouped under Pleistocene to Holocene age. Other deposits included in this are Tapi-Narmada-Godavari alluvia, high level terraces, talus fans in frontier region of Nepal and Tarai area, extensive deposits of laterite in Peninsular India and wind blown sands of Rajasthan, Kutch deserts and Maharashtra etc.

The igneous activity has manifested itself in the intrusive, hypabyssal and extrusive forms in several parts of the country during its long and varied geological history. The Peninsular region abounds in igneous suites of rocks. Apart from metavolcanics associated with the Dharwars and post Dharwar basic and ultrabasic igneous rocks, three periods of post Dharwar granitic intrusions have been broadly recognized in South India *viz.* (a) Champion Gneiss, (b) Peninsular Gneiss and (c) Closepet Granite. Another suite of rocks ranging in composition from acid to ultrabasic is known as Charnockite Series. There is a considerable difference of opinion on the origin of these rocks. Granites of various generations have been recognized in other parts of Peninsular India but their specific ages are yet to be worked out. However, recently Berach Granite, Untala Granite of Western India; Singhbhum Granite and Chakradharpur Granite of Eastern India have been assigned Archean age whereas Bonai Granite of Orissa, Bundelkhand Granite of Central India have been assigned Archean – Proterozoic age. The Proterozoic acid igneous rocks include Arkasam Granophyre, Mayurbhanj Granite of Eastern India; Dongargarh Granite of Central India; Closepet Granite if S India; Erinpura Granite of Western India and Granitoid of Bandal, Chor, Lingtse of Himalaya. Basic and ultrabasic suites of this age include Gabbro and Anothosite of Kerala; Andhra Pradesh and Orissa; Ultrabasic of Rakhabdev, Phula Ophiolite of Western India. Alkaline suites include Kishangarh Syenite of Rajasthan and Alkali Complex of India. The Upper Proterozoic-Palaeozoic igneous suites include Kaplas, Dalhousie and equivalent graintoids of Himalaya and Mylliem Granite and equivalents of Assam and Meghalaya. Granitoids of Ladakh-Karakoram, Lohit have been assigned Mesozoic-Tertiary and Mesozoic ages whereas some granites have been assigned Tertiary ages also.

Recent volcanic activity is known only in Barren and Narcondam islands. The hypabysal and volcanic rocks include the Ophiolites of Andman-Nicobar Islands of Mesozoic age and Sangeleuma Group with ophiolites in Indus Belt of Western Himalayas; volcanic rocks of acidic composition belonging to Proterozoic age include Malani Rhyolites of Western India; Bijli Rhyolites, Pitepani Andesite of Central India and those of basic compositions include Cuddapah Traps of South India; Dalma Volcanics, Ongarbira Traps and equivalents of NE India. Panjal Volcanics of Western Himalaya with Agglomeratic slates belong to Upper Carboniferous to Lower Permian age. Jurassic-Cretaceous basic igneous activity is represented by Rajmahal Traps of Eastern India and Sylhet Traps of NE India. Basic Volcanics of Karakoram represent Cretaceous-Triassic and Mesozoic basic activity whereas most wide spread Deccan Traps of Western and Central India; Abor volcanics of NE Himalaya and Dras volcanics of Western Himalaya represent the igneous activity of Cretaceous-Palaeogene period.

3.1 Structure Tectonics and Seismicity

In case of structure, tectonics and seismicity also India can be divided into two domains i.e. Peninsular domain and Extra-Peninsular domain that includes northeastern region. The extra-peninsular region that includes Himalayas is plate margin region as it lies on boundaries of India Plate as seismicity is interplate seismicity, whereas Peninsular domain is termed as interior region or intra plate domain and seismicity is of intraplate nature.

3.1.1 Structure and Tectonics

The Himalayan Tectogen can be divided into four principal longitudinal tectonic belts on the basis of their characteristic geological attributes. The Karakoram Belt is the northern most , which is followed in south by the ophiolitic mélange and plutonic zone of Indus-Shyok Belt. Main Himalayan Belt that contains the complex fold thrust tectono-stratigraphic stack follows this. The Frontal Fold Belt is the southernmost belt, which contains essentially the Tertiary rocks of the Foreland Basin (Kumar et al, 1989). Prominent dislocation zones bound most of these tectonic belts. The Main Central Thrust (MCT) is the most significant tectonic zone whose location and significance are debated. The bulk of the rocks of the Main Himalayan Belt are Proterozoic and they contain structures of polyphase deformation and imprints of polymorphism. The possibility of existence of vestiges of pre-Himalayan structural and metamorphic imprints is recognized. The Frontal Fold Belt is a schuppen zone bounded by Main Boundary Thrust (MBT) in north and Foot Hill Thrust (FHT) in south. On the basis of lithostratigraphy, available geochronology, palaeontological controls, a palaeogeographic evolution of Himalayas has been worked out. In addition to above there are other tectonic planes parallel to Himalayan trend in different sectors which include South Almora Thrust, Tons Thrust, Garhwal Thrust, Panjal Thrust, Sudh Mahadev Fault, (Jangpangi et al, 1986) etc. in Western Himalayas. In addition to NW-SE trending faults and thrusts, there are a number of cross faults trending NNW-SSE to NNE-SSW like Kishtwar Fault (J&K), Sunder Nagar Fault in H.P, Dwarahat Fault in Kumaon, the faults in Bhutan, Bame Fault in Arunachal Pradesh. Except Bame Fault, all other faults are right lateral. Narula (1991) has recognized the different seismic characters in different seismic blocks bound by these transverse faults. A number of hypotheses have been propounded on the evolution of Himalayas. The Himalayas have been considered a classic product of a continent-to-continent collision. They display complicated seismotectonic set up with high level of seismicity and have witnessed four large earthquakes during past one century. According to Conaghan & Powel (1973) the Himalayas evolved in two phases of tectonism, the first phase relating to subduction of Indian Plate beneath the Eurasian Plate and culminating into continental collision after oceanic material inbetween had been completely consumed. Because continental lithosphere of India is too buoyant to subduct the collision has been accommodated by the uplift of the Himalaya and the Tibetan Plateau as well as lateral expulsion of parts of lithosphere away from collision zone. In response to the continued plate convergence, the collision, boundary shifted southward and northern leading edge of Indian Plate thrust back on to itself (Acharya & Narula, 1998). At either end of collision are sharp kinks or syntaxes. The NW syntaxis is associated with the Pamir and Chaman Fault system whereas NE syntaxis is associated with the linkage of Eastern Himalayas with Indo-Burmese Range (Acharya & Sengupta, 1998). Narula et al (1989) synthesized the data available on neotectonic features, the recent nature of movement along them from Himalayan Region. This data indicates that neotectonic activity has been recorded along a number of thrusts like MBT1, MBT2, Markanda Thrust, Sarpduli Dekata Thrust, Satlita-Soan Thrust etc. Apart from these, a number of transverse tectonic surfaces like Ravi Tear, Tundi Fault, Yamuna Tear, Ganga Tear, and Kosi Wrench Fault have demonstrated that those were active during recent times.

In the evolutionary history of Indian Peninsula several episodic changes have taken place from time to time that have left their imprints on the rock and land mass. The drifting of shield segments, opening and closing of oceans, orogenic movements, development of mobile belts and extensive rifts are some of the important tectonic phases associated with Precambrian times. Vast areas of Indian Shield comprise basement of Archaean Crystalline represented by granite, gneisses and schistose rocks. Faulted basins and grabens were subsequently formed in the basement, which were occupied by the sediments belonging to Proterozoic, Palaeozoic and Mesozoic ages. Extensive parts of Western and Central Peninsula including Deccan Plateau, Western Ghats, Narmada Graben, Kathiawar and Kutch were flooded with Basaltic lava flows during Late Cretaceous-Early Tertiary-Quaternary period though minor movements continue to take place even in present times. The important structural elements of Peninsula include the Dharwar Craton separated from the Pandyan Mobile Belt along the Cavery River Fault (Fig.-2). The major shears in transition suture zone of the two tectonic blocks include Bhavani, Moyar, Kabini and Bhavali lineaments. The Dharwar Craton is divided into eastern and western blocks by the Chitradurga Boundary Thrust and in the northeast is separated from the Eastern Ghat Mobile Belt by the Cuddapah Eastern Margin Thrust. The crystalline-sedimentary boundary fault is parallel to east coast and is displaced at number of places by WNW –ESE trending cross faults. In Western Ghats, the NNW to NW trending system of lineaments related to West Coast Fault is predominant. The other major fracture and shear zones include Achankovil, Balehonur, Bababudan and Kerala lineaments. In the central part of Peninsula three distinct lineament patterns have been identified which are ENE-WSW Satpura trend, NW-SE Godavari trend and N-S Sahyadri trend besides NE-SW trend of Bundelkhand Block, NW-SE trend of Vindhyan Platform and NW to NE trend of Bastar Plateau (Rajurkar et al, 1990). The most spectacular of all these referred to as SONATA Zone is marked by Narmada-Sone Lineament in the north and Tapti Lineament in the south with the Satpura forming the median host. The major lineaments associated with the Godavari trend include that of Kaddm, Ghod, Upper Godavari and Varna. The Sahyadri trend confined to narrow zone is parallel to West lineament trends north of SONATA is altogether different from that over the Satpuras. In north, NNE and NE trends in addition to minor NW and NS lineaments mark the Aravalli Block. In its western parts, the most important structure is that of N-S trending Cambay Graben. In the Kutch and Saurashtra regions the mega lineaments adopt trends of E- W to NE-SW.

3.1.2 Seismicity

The seismicity patterns in India vary widely. The map showing epicenters indicate that epicenter of major and medium magnitude earthquakes are concentrated in Himalaya and North East India whereas isolated clusters can be observed in rest of India. Similarly, the concentration of seismic events can also be observed around Andaman and Nicobar Group of Islands (Fig. 3). Based on past experiences, concentration of epicenters of seismic events, accelerations generated, due to these and seismotectonic set up, the country has been divided in four seismic zones i.e. zone II to V as per map of India showing seismic zones (IS 1893 Part-I : 2002). This map (Fig. 4) shows that zone-V, having highest degree of seismicity is observed in Himalayas, NE India, Kutch region of Gujarat and Andeman and Nicobar Islands whereas parts of Madhya Pradesh, Chhatisgarh, Karnataka and Tamil Nadu have been kept in zone II i.e. lowest seismic zone.

The Himalayas comprising a part of Alpide-Himalaya Seismic Belt are known for high seismicity. This largest active continent to continent collision zone has witnessed four large magnitude earthquakes from 1897 to 1950. In addition it had nine more events with magnitude 7 in last one century. It is observed that most of the seismic energy has been released along a narrow belt around the map trace of MBT and MCT except around the Western syntaxis and in the NE where siesmicity patterns are more complex (Fig. 5) The siesmicity patterns and contemporary deformation styles have been explained through different models like (i) Steady State Model (Seeber el al, 1981) and (ii)

Evolutionary Model (Ni and Barazangi, 1984). Depending upon the discrete deformation styles and seismic behaviour, Narula (1991) had classified different seismo-tectonic domains of NW Himalayas into several Seismo-tectonic Zones. Those are Main Himalayan Seismic Zone, High Himalayan Seismic Zone, High Plateau Seismic Zone, and Kashmir Syntaxial Seismic Zone. Another Complex tectonic model with involvement of NE projection of Indian Shield against the south directed, trans-Himalayan Thrust sheets has been presented for NE Himalayan foothills and eastern syntaxis bordering the Siang Window (Acharya & Sengupta, 1998). Northeast India has complex tectonic and seismo- tectonic setting (Fig. 6), this is caused by the juxtaposition of three tectonic blocks such as NE projections of Indian shield, and Himalayan Thrust front and its eastern syntaxis, and the thrust imbricates Indo Burma Block. Kayal (1997), on the basis of analysis of data observed during last hundred years indicated that the seismic activity appears to be sparse in eastern Himalayas and the same is high in the syntaxial zone. In case of Indo Burma Ranges, the earthquake epicenters are highly concentrated and aligned in NNE-SSW direction and activity is intense and uniform up to a depth of 200 km up to 26° and there is marked shallowing of lower limit of activity beyond this where collision process has taken over subduction process. The siesmicity in Shillong Plateau, Mikir Hills and Assam Valley area is characterized as plate-boundary zone activity. This activity is quite high in Shillong Plateau as well as in Mikir Hills area. The Bengal Basin is also characterized by low seismic activity whereas moderate activity is observed in Tripura area. The activity of Bengal Basin may be related to intra plate activity. In Kutch and Saurashtra region the Wegu lineaments adopt trends of E-W to NE-SW. The catalogue of earthquakes in Peninsular India for the period from 1341 AD to 1991 AD lists a total of 1020 events with M> 3. The correlation of siesmicity patterns with the tectonic framework of southern Peninsula indicates cluster of epicenters between Mysore and west of Pondichery is located close to Dharwar Craton-Pandyan Mobile Belt and cluster located east of Mangalore probably related to the West Coast Fault. The cluster of epicenters including Bellary Earthquake is related to Chitradurga. Boundary Thrust. Similarly many isolated incidences and clusters have been related to some or other lineaments and fault systems. The concentration of epicenters in central Peninsula is confined mainly along the Sonata and Sahyadri trends and Godavari Graben. In the western part, the clustering is mainly along Cambay Graben and Rann of Kutch. Chandra (1977) has identified 13 distinct seismic zones in Indian Peninsula corresponding with the major tectonic elements. Many areas where swarm micro seismic activity has been observed are Nanded, Jabalpur, Koyna, Thane-Bhatsa, Iduki, Parbhani, Khandwa, Kozikode, Bidar, Sehore, and Vizianagaram etc. The seismic hazard status of the Indian Peninsula according to Pande (1999), one considered as a very stable region has undergone several modifications as more and more data has became available but still there are large gaps in the data base and understanding of the seismotectonic behaviour of various domains and is purely tentative as on today (Fig. 7).

4.0 LANDSLIDES FLOODING AND SEDIMENTATION

The history of mankind is replete with the instances of widespread devastation due to natural phenomena like earthquakes, landslides, avalanches floods, cyclones, draughts and volcanic eruptions. Natural calamities are believed to account for up to 4% of total annual deaths. Globally, the landslides cause approximately 1000 deaths every year with property damage of about US $ 4 billion apart from contributing heavily towards siltation of rivers and reservoirs. India, a country of diverse physiographic and climatic conditions, has to face the vagaries of different natural hazards including landslides off and on. Landslides, a major natural hazard with which a considerable area of the country has to contend with every year, is brought in its wake by monsoons, rainstorms and earthquakes in the hilly tracts of Himalayan Region, Nilgiris, Eastern and Western Ghats (Fig - 4). These are characteristic feature of Himalayan Zone in the Extra Peninsula which is marked by the presence of large number of landslides that are either active at present or dormant. The slope un-stability in Himalayas and NE India can be related with geology, geomorphology, seismo-tectonic set up and geodynamics (Fig.- 9). All these factors along with climatic factors and land use pattern are important in inducing slope instability such as fragile nature of rocks, active nature of tectonics in plate margins combined with high rain fall, heavy deformations and incursion of man into virgin areas are main causes for dotting the hill slopes with landslides . These along with other causes become some of the major contributors to the silt load in the case of Himalayan rivers and this leads to floods and ultimately silting up of river beds in middle and lower reaches. As the tree roots in the soil rot away, the steep hill sides become more prone to increased frequency of landsliding. The soil thus mobilized by erosion and rubble generated by landslides is dumped in streams and the river channels causing aggradation of river beds and sometimes even peninsular streams are buried beneath the channel debris. During monsoon, phenomenon of landslides assumes higher frequency because of saturation of soil and increased intensity of the erosion. Deforestation and road construction also invariably increase sediment load due to increased landslide activity. The part of the problem of increased sediment loads and higher flood peaks is passed down the stream affecting areas and people hundreds of miles away from the deforested landslides. The Alaknanda flood of 1970 left 2 m thick deposits of debris at Srinagar (Garhwal),100 km away from the flood source and blacked a 10 km reach of the Ganga Canal near Haridwar 300 km from the flood source. Landslide activity, though not very common in the Peninsular India is confined to certain areas in Western Ghats and Nilgiris (Fig. 8). Deep weathering in rocks, presence of thick overburden on steep slopes of competent rocks and high rainfall are factors responsible for inducing instability in slopes. Since these are very restricted in space and contribute very little to siltation in Peninsular region. Hill slope and mass movements of various types also exert an important control on silt load of rivers. Rock falls, debris flows, landslides and other slope failures occur frequently, supplying coarse and fine sediments that affect the channel morphology and these are mobilized during the floods. Some times huge landslides completely the block the river courses in Himalayan region and millions of tons of debris/ silt are transported in very short period of time when such blockades are breached away.

Heavy rainfall has been the main cause of floods in any river basin in India. Besides meteorological conditions, there are other factors both natural as well as man made which are responsible for causing floods in the rivers. The problem of flooding is closely related with siltation. Sometimes the floods, especially when these recede, cause heavy siltation in certain reaches where energy conditions favour the same resulting in drainage congestion. The reverse is also true as drainage congestion also results in floods. Various energy conditions develop in different domains in a river system at various points of times resulting in erosion in certain reaches and deposition at others. The intensity of erosion and energy conditions in a particular reach are responsible for defining the carrying capacity of the river. The change in energy regime results in offloading its load leading to siltation in that particular reach. But further change in energy regime in future could also result in nature of river at same location which may start eroding the sediments deposited earlier. A study shows Ganga river in aggradation stage at Allahabad, Shahzadpur and Mirzapur on average. Similarly Gomti was aggradational at Sultanpur but degradational at Jaunpur. However, at micro level, out of 10 cross-sections at Allahabad, 7 indicated the Ganga to be in aggradation. whereas at 3 locations it was degradational. Similarly in case of Gomti at Jaunpur, 3 cross sections indicated it to be degradational while 2 indicated that the river was in aggradation stage. Same is the case with Tons at Mejspur and Gomti at Sultanpur where on micro scale river was indicated to be in degradation at 4 locations out of 10. Similar pattern was observed in case of Ganga at Varanasi. But in case of Brahmputra, the river was found to be in degradation stage in all the three cross-sections at Panchratna. A study carried out to study the behaviour of the river Brahmputra through 600 cross sections between 1957 and 1971 indicated that there was no significant deposition or scour over entire length of river. However, scouring and deposition in different reaches is not uniform. During this period, aggredation of about 6.35 cm per year and scour of 6.85 cm per year appears to have taken place at different locations. In a reach aggradation and degradation are not steady and continuous phenomena but are event specific and temporal. Goswami (1985) divided 145 km length of Brahmputra from Kobo to Bessaucara in 15 segments with a view to study agradation and degradation. Results indicated degradation in initial 3 reaches, aggradation in next two reaches followed by degradation in subsequent four reaches, aggradation in two reaches and degradation in last four reaches. According to Sinha & Jain (1998), the coarse and medium factions are interpreted as temporarily suspended bed load whereas fine fraction is the wash load or long term suspended load. As per the estimates of Dedkov and Mozzherin (1984), suspended sediment yield in relation to drainage basins in varies from 100 to >250 tons/ Km Sq/year (Fig.- 10).

In floods the velocities increase monifold, the sediment carrying capacity thus increases several hundred times. Thus huge amount of load is discharged in similar quantities if the velocity decreases. This is all the more true during the period when the floods recede, the already vulnerable sites become more critical as far as sedimentation is concerned. Out of total components of sediments load, the total dissolved load increases with the increase in discharge. The rate of bed material transport is almost entirely a function of transporting capacity of flow. The rate of wash load transport is principally determined by its rate of supply from drainage basin which depends on overland basin characteristics.

In case of Brahmputra as stated by Goswami (1998), the basin represents a unique physiographic setting vis-à-vis eastern Himalayas, a powerful monsoon fed regime under wet humid conditions, a fragile geological base and active siesmicity. The gradient is as flat as 0.1 m/km. The Brahmputra is underlain for most part by very young and sedimentary formations and hence carries mainly fine sand and silt with very little clay. The river is ranked fourth among the largest rivers of world with an average annual discharge of 19830 $m^3 s^{-1}$ at mouth. Brahmputra is one of the major sediment transporting large rivers of the world and the sediment transported per unit drainage area 1128 m tons/km^2/year at Bahadurabad in Bangladesh and same is only 804 m tons/km^2/year at Pandu near Gauhati. According to Goswami (1985), during monsoon months the Brahmputra carries an average annual daily sediment load of 2.12 million metric tons of sediments at Pandu. A similar study was carried out by GFCC on the river Kosi in 1980. In this, whole length of river from Birpur to its confluence with Ganga was divided into 6 reaches. The results indicated that four reaches were of aggrading nature and degradation was indicated in two reaches. Thus it may be concluded that average may not reflect true picture and studies have to be site specific.

The sediment yield estimates for Himalayan rivers vary widely. Suspended sediment measurements for rivers in Nepal are 1000-8,200 tons/km^2/year (Laban, 1978) but actual yields are believed to be 2.5 times higher (Galay, 1987). Sediment yields for rivers throughout the Himalayas range from 40 tons/km^2/yr at Lhasa in to 510 tons/Km^2/year on Indus river at Kotri in NW Himalaya and 12510 tons/km^2/year at lower elevations in NE Himalayas. This variability in discharge reflects variability in silt load, from humid subtropical low lands in east to arid northern and NW valleys. The magnitude of sediment transport and channel change resulting from any single flood will be strongly controlled by the magnitude of the flood preceding it. Constant sediment transport from unstable slopes to the valley bottom will introduce coarse clasts that normal flows may not be competent to transport through wider, lower gradient depositional reaches. Normal flows will incise a channel into valley bottom fill, but the size of this channel will be greatly increased during large floods. Following the flood, the process of gradual decrease in size of channel will begin again resulting in deposition.

The lateral expansion of river channel and decline in their slope in the mountain foreland causes the flattening and reduction in the energy of flood waves as reflected in extensive deposition over the alluvial fans. At the mountain margins, extending for a distance of 2 km in West Bengal, is a sector of fans characterized by gravel and boulder. These are reworked during floods. This belt forms a swell over extensive fan plains with low gradient. Coarse boulders rapidly disappear due to a drop in competence of the river. This zone is characterized by abrupt changes in channel geometry and high deposition rate. The rate of deposition during last 10 years may be estimated up to 1-3 m.The analysis also indicates sediment concentration in rivers of Bihar like Gandak, Kosi, Burhi Gandak, Baghmati and Kamla Balan is much more during monsoon period as compared to non-monsoon period. This is because energy level in the river is much higher due to more discharge in rivers as compared to that in general, the average sediment load of mountain fed rivers is much higher than that of foothill fed and plains fed rivers which is essentially a function of their large catchment areas. The sediment yield values also reflect that these values are higher for small systems like Kamla Balan and lower for large systems such as Kosi.

In the middle reaches of the river in plains over bank flooding is such a dominant and frequent phenomenon that it influences other fluvial processes operating in area and one such process is bank erosion which is affected most. Other processes of influence are channel morphology changes, sediment transport behavior and overall evolution of flood plain. Bank erosion is one of the most commonly experienced effects of high flow in plains where bed gradient of the river is low. It is essentially governed by the stream power (**τV**), where **τ** is shear stress acting on bank and **V** is velocity of flow. As the discharge of a stream increases, depth and mean velocity also increase due to which river banks are subject to greater erosive action. Empirical relation between velocity and discharge given by Richards (1977) is $V = a\,Q^{b}$, where **a** and **b** are variables dependent on cross section of river. This indicates that increase in discharge would result in high stream power of flow that would cause more bank erosion. In a meandering river with flood plain, the increase in discharge yields high transport capacity.

5.0 QUANTIFICATION AND IDENTIFICATION OF VULNERABLE REACHES

The stream erodes sediment from its bed to keep pace with an increasing equilibrium rate, but there may be limit of sediment availability, either due to supply or bed resistance. To maintain the equilibrium rate between sediment and discharge, the flow attacks the bank and hence river widening occurs because of high discharge. Most rivers in plains are characterized by rapid and frequent changes in stage and discharge that reduces the resistance to erosion of bank material. The main erosional process operating along the riverbank is large scale slumping. It appears that following the saturation, the bank material becomes unstable and slides along the curved shear planes in large blocks. The sediment load in the river channel is contributed through erosion in the catchment area, bank erosion, bed erosion and due to overland flow. The erosion processes can be analysed as the dynamic action of the forces on resistant geological material. As the severity and effect of hydraulic forces increase many fold during flood, the rate of erosion increases rapidly in case of flooding. The effectiveness of flood erosion depends on exceedence of a resistance threshold in bed or bank materials, including vegetation. Alluvial channels with noncohesive beds and banks provide minimum resistance to erosion and hence contribute a large amount of sediment load. While the cohesive sediments offer greater resistance and hence lesser sediment input, the amount of sediment carried by the stream flow is governed by the velocity. As the velocity doubles, the sediment particles carried would increases 64 times and vice versa.

According to Seth (1998), major flood affected areas lie in Brahmputra-Ganga-Barak basins and the problems of floods and siltation vary from basin to basin depending upon geomorphology, land use, physiography, siesmicity, geology and tectonics. In general the flood problems increase from west to east and from south to north. In extreme NW parts there is problem of drainage congestion. It also exists in southern part of West Bengal resulting from siltation of channels. The flooding and erosion problems are serious in the states of Bihar, U.P. and West Bengal. Due to sediment deposition, the waterway of river gets considerably reduced. Similarly Kosi river carries highest sediment load and it is estimated that 2.2 billion metric tons of sediments are transported each year by Ganga-Brahmputra rivers.

The NW rivers *viz* Indus, Chenab Jehlum, Satluj, Ravi carry large volumes of sediments which are deposited leading to rising of river beds.

In case of Peninsular rivers, the problem of siltation is heavy in deltaic areas.This indicates that it is very difficult to quantify the siltation but but since the siltation is directly linked to the erosion in upstream areas of catchment, the problem can be partially handled by identifying the erosional reaches which contribute to siltation quantifying the rate of erosion and making attempts to reduce the quality of siltation rather than trying to stop the siltation. Some attempts can be made to alter the morphology of river in this area so that rate of siltation is reduced.

Hill roads are the cause of many landslides and act as major sources of sediment. Estimates of the rates of sediment production by roadways in the Central Himalaya run from 430-550 cubic meters/ km of roadway/year (Patnaik 1978, Valdiya 1988). However the results of detailed case studies suggest that these figures may be on conservative side (Bansal and Mathur,1976; Haigh, 1988b).

Landslides, however, are more widespread, and according to popular belief, their frequency is rapidly increasing (Bhatt 1980, Bahuguna 1982). Despite this Meijerink (1974), working in the Aglar valley of Garhwal, calculated that superficial debris slides generate only 5 kg/ha/year of debris of which a fifth reaches the river channel. He also calculated that the catchment's long term, geological sediment yield is 0.09 – 0.45 Mg/ha/year. By contrast, soil losses as high as 156 Mg/ha/year have been measured on 8% slope tilled fallow in the Dehra Dun area.

Dhruva Narayana (1987) estimates the sediment yield of the Tehri Dam's catchment as 19.4 Mg/ha/year. The sediment loads carried by Himalayan rivers can be very high. Das (1987) sampled the sediment loads of the Bhagirathi rivers above the new Tehri High dam in Garhwal. He concluded that between July and October, these rivers carry a silt load of the order of 2 kg/cubic metre respectively.

Many channels in the area raise their beds by up to 10 cm a year (Bahuguna 1987). Sediment choked channels are not uncommon in the hills, especially in areas close to construction activity. The sediment is supplied by deforestation, road construction and clearance, and by landslides that are often activated due to the channel itself. A survey of a kilometer reach of second order channel in a deforested area below Mussoorie in 1978 discovered 9 fresh landslides of more than 20 cubic metres contributing more than 1,0000 cubic metres to the channel bed. However, the most spectacular illustration of this process is to be found at Rajpur near Dehra Dun. Here, in 1919, the Kaulagarh Bridge was built across a small perennial stream. The bridge soffit cleared the bed of the perennial rock floored stream by 19.5 metres. However, the upstream, deforestation triggered landsliding which dumped an enormous volume of sediment in the channel. In 1979, the bridge cleared a wide boulder run by just 1 metre (Photographs in: Haigh 1984a, Nossin 1971).

6.0 CONCLUSIONS AND RECOMMENDATIONS

The enormous work and the consequent maps and data generated in the fields of seismotectonics and seismic zonation, landslides and landslide hazard zonation, neotectonism and geoenvironmental studies can be made use of while studying the problems of siltation of Indian rivers and their management. Chopra (1980-81) carried out siltation studies in part of Bhakra catchment area using geomorphological parameters. Deva (2001) carried out sediment source mapping in Dhemaji district of Assam in Jiadhal river basin. He proposed a comprehensive rapid catchment analysis aimed at isolating critical sediment generating sectors for fixing catchment management priorities. The methodology used is quantitative and involves preparation of a sediment generation potential contour map of the basin based on Ruggedness Number, ground erodibility and vegetation cover. Such studies can be taken up by different agencies as a time bound programme for rapid analysis, quick appraisal and management. Another work by Sharda and Bagchi (2001) in the Kandi watershed area in Punjab involving small rivers with small catchment areas. Since hydrological parameters in case of small streams are not available everywhere due to paucity of observed data, therefore these have to be estimated through indirect methods and these estimates sometimes go off the mark considerably. Keeping this in view they made an attempt to analyse the influence of various geomorphic parameters. Based on multiple regression analysis, runoff factors and rate of siltation were estimated. They concluded that correlation of geomorphic values with those of rainfall and land cover yield dependable results in case of estimation of runoff factor and rate of siltation. Similar studies could be undertaken in other similar small catchments for estimation of rate of siltation. It may also be concluded that site specific studies and data collection has to be carried out to determine whether a site is of aggradation or degradation nature and no single method can succeed in controlling the phenomena.

An outline action plan for siltation studies of Indian rivers is suggested below:

1. Setting up of a network of sediment data observation stations vis-à-vis existing stations similar to the discharge/gauge/station network
2. A rapid appraisal of critical areas for immediate catchment area management by suitable methods.
3. A rapid appraisal of critical reaches of different river systems for desilting by appropriate methods based on geomorphological, hydrological and other studies.
4. A long term national action plan for siltation control in major Indian rivers and disiltation of major/medium/minor rivers in the light and ambit of different watershed catchment areas as envisaged in the New Water Policy recently announced by the GOI.

National watershed Catchment Area. Authorities for different river systems manned by experts in the field of Geology, Hydrology & Civil Engineering need to be set up for long term planning and perspective and to achieve the targets in the fields of hydroelectric development, flood control, silt control, irrigation, drinking water augmentation, inland waterways and related social & economic development programmes.

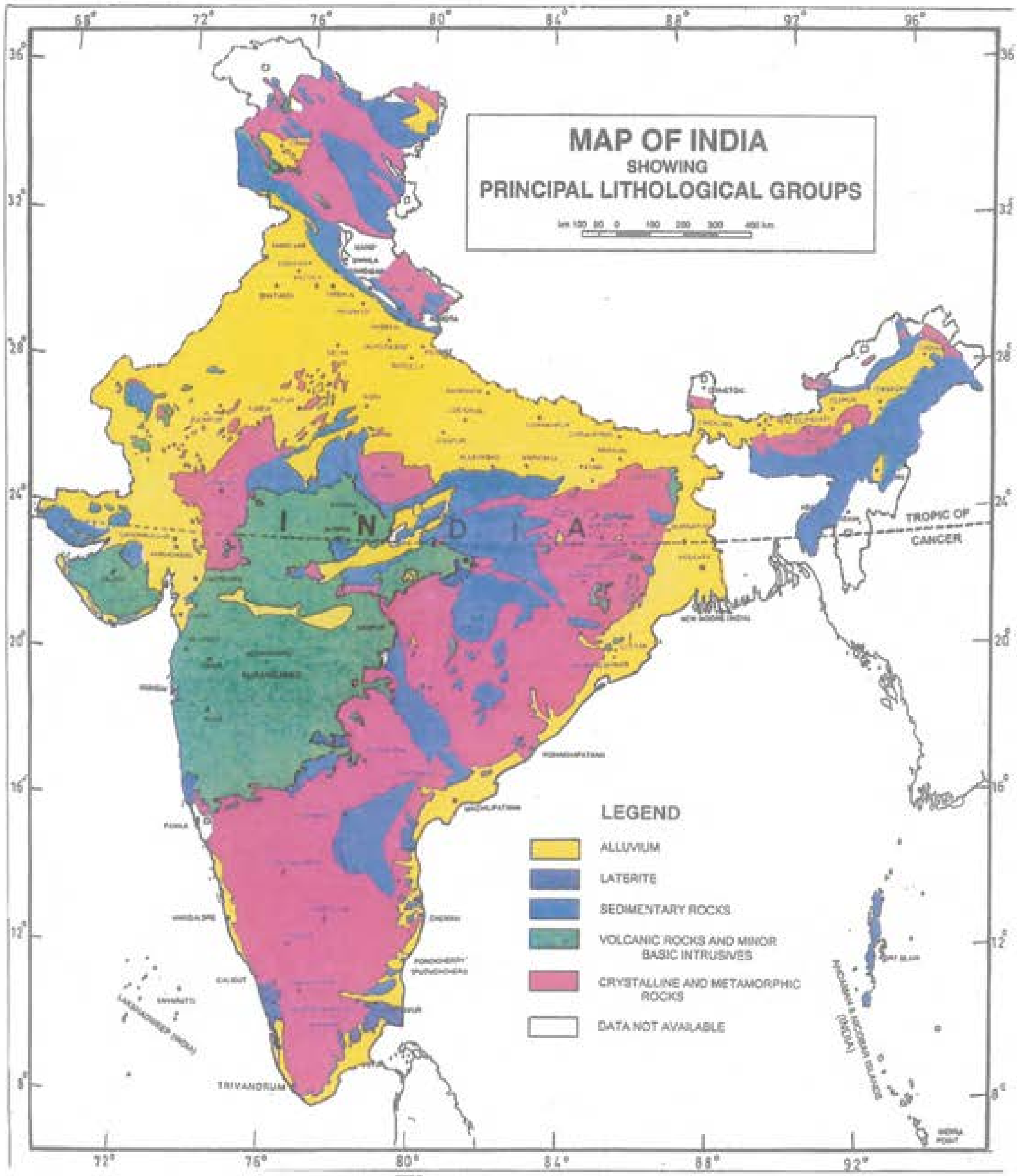
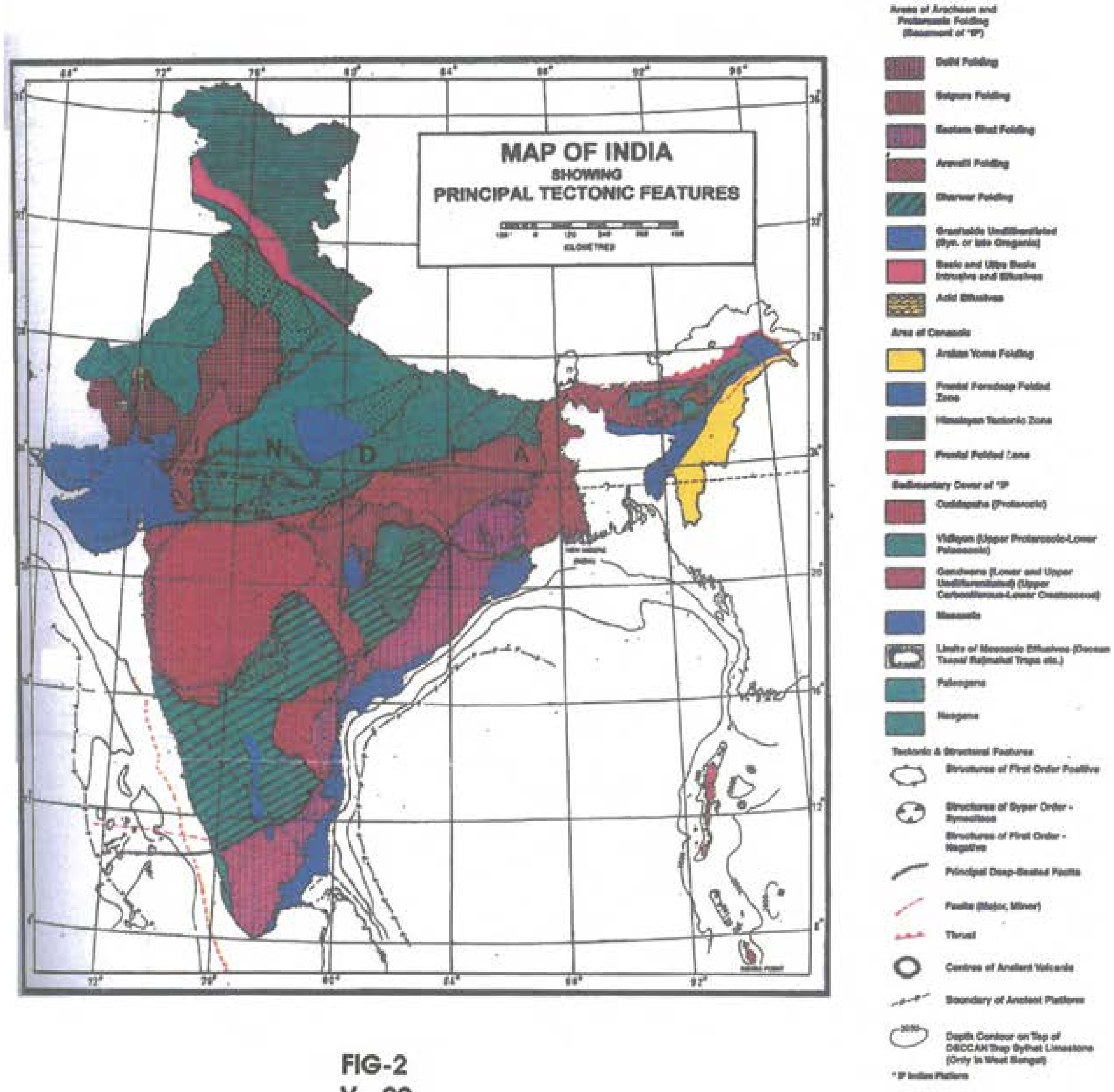
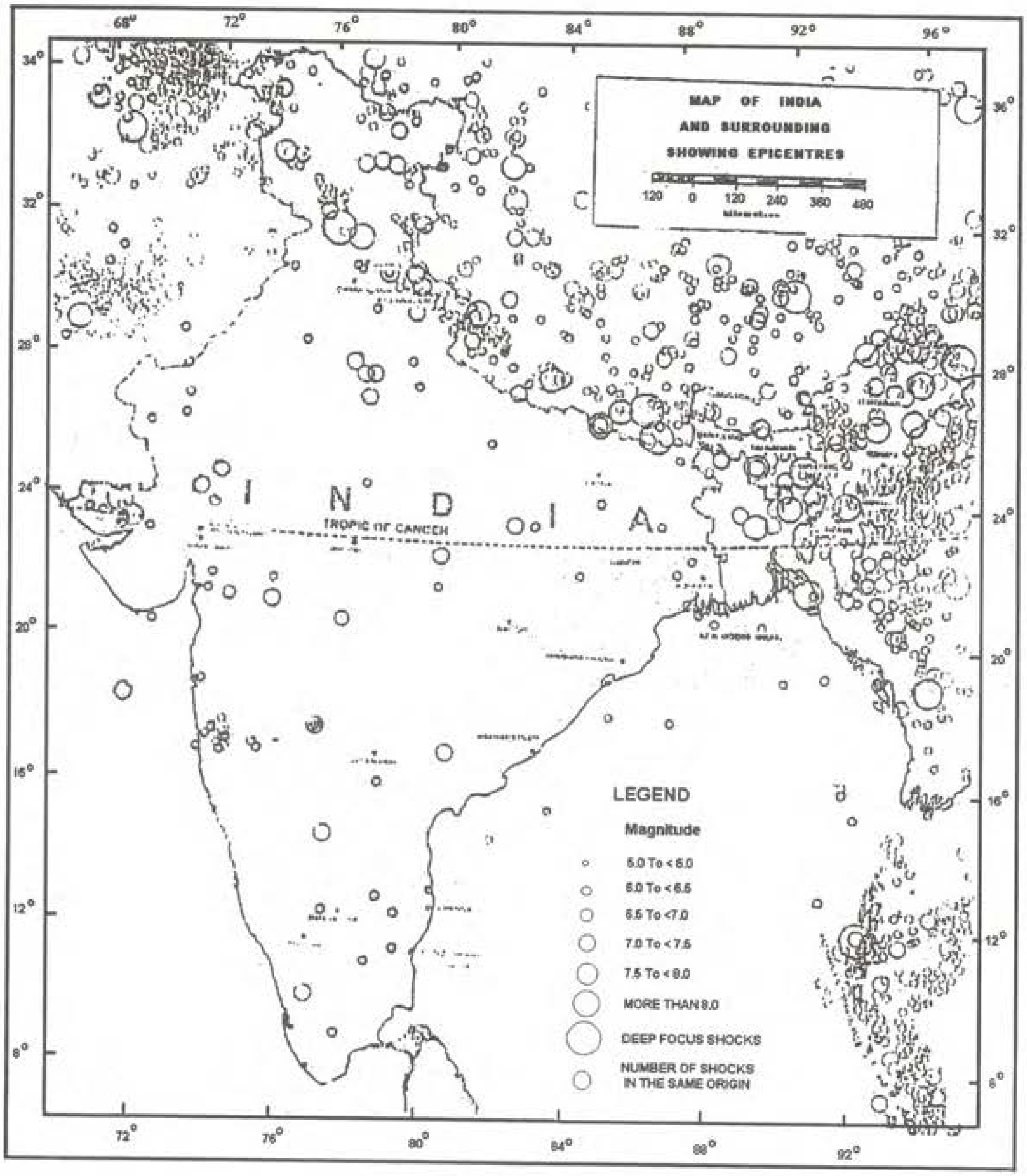

MAP OF INDIA
SHOWING
PRINCIPAL LITHOLOGICAL GROUPS
I N D I A
TROPIC OF CANCER
LEGEND
ALLUVIUM
LATERITE
SEDIMENTARY ROCKS
VOLCANIC ROCKS AND MINOR BASIC INTRUSIVES
CRYSTALLINE AND METAMORPHIC ROCKS
DATA NOT AVAILABLE
TRIVANDRUM

Fig.-1



MAP OF INDIA
SHOWING
PRINCIPAL TECTONIC FEATURES
I N D I A
Acid Effusives
Arakan Yoma Folding
Himalayan Tectonic Zone
Palaeogene
Neogene
Tectonic & Structural Features
Structures of First Order Positive
Principal Deep-Seated Faults
Faults (Major, Minor)
Thrust
Boundary of Ancient Platform
Depth Contour on Top of DECCAN Trap Sylhet Limestone (Only in West Bengal)
Data Not Available

FIG-2
V - 22


MAP OF INDIA
AND SURROUNDING
SHOWING EPICENTRES
120 0 120 240 360 480
I N D I A
TROPIC OF CANCER
LEGEND
Magnitude
5.0 To < 6.0
6.0 To < 6.5
6.5 To <7.0
7.0 To < 7.5
7.5 To < 8.0
MORE THAN 8.0
DEEP FOCUS SHOCKS
NUMBER OF SHOCKS
IN THE SAME ORIGIN

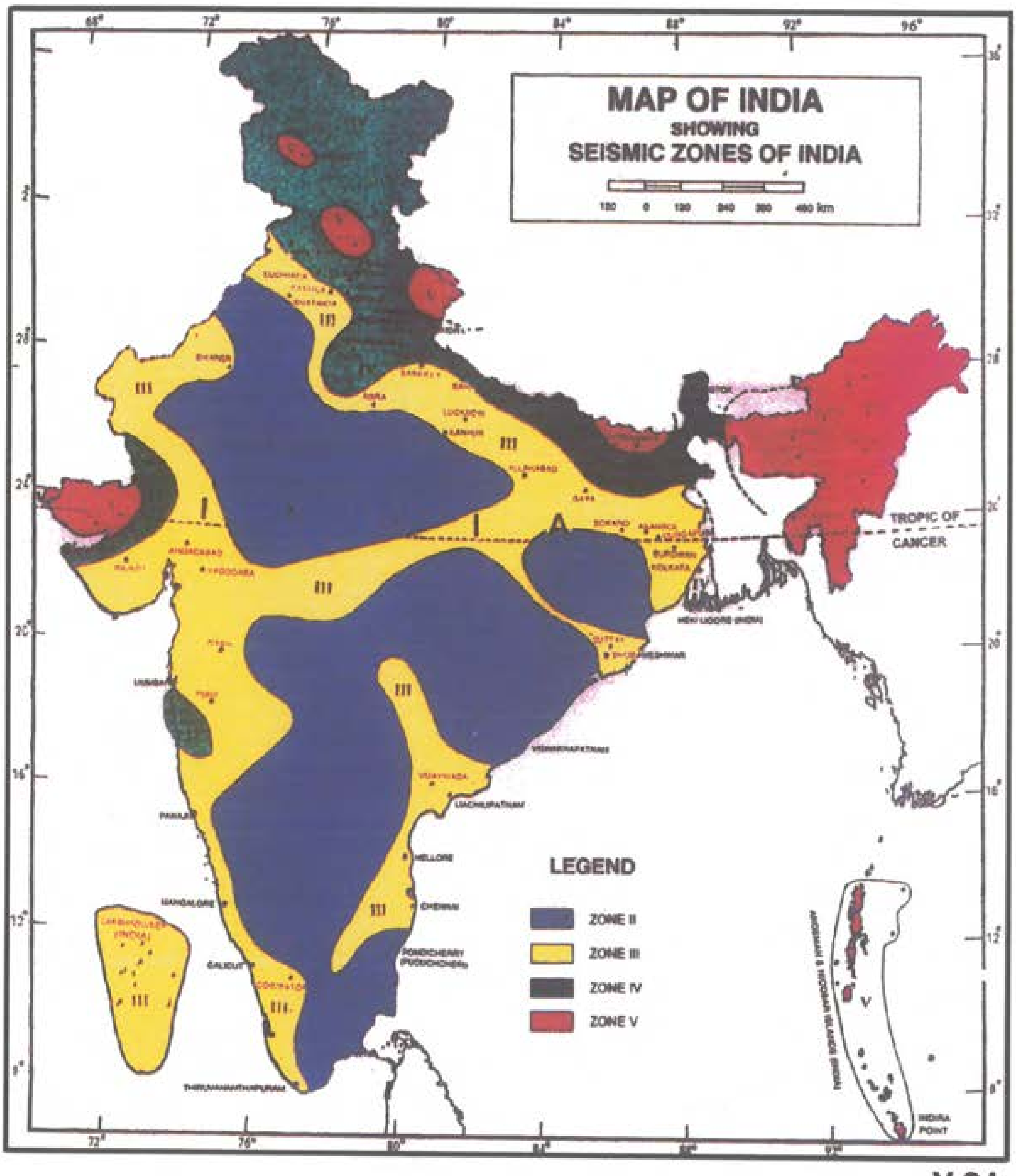

MAP OF INDIA
SHOWING
SEISMIC ZONES OF INDIA
LEGEND
ZONE II
ZONE III
ZONE IV
ZONE V
TROPIC OF CANCER
LUCKNOW
KOLKATA
VISAKHAPATNAM
MACHILIPATNAM
CHENNAI
PONDICHERRY (PUDUCHCHERI)
MANGALORE
CALICUT
THIRUVANANTHAPURAM
INDIRA POINT

FIG.4.

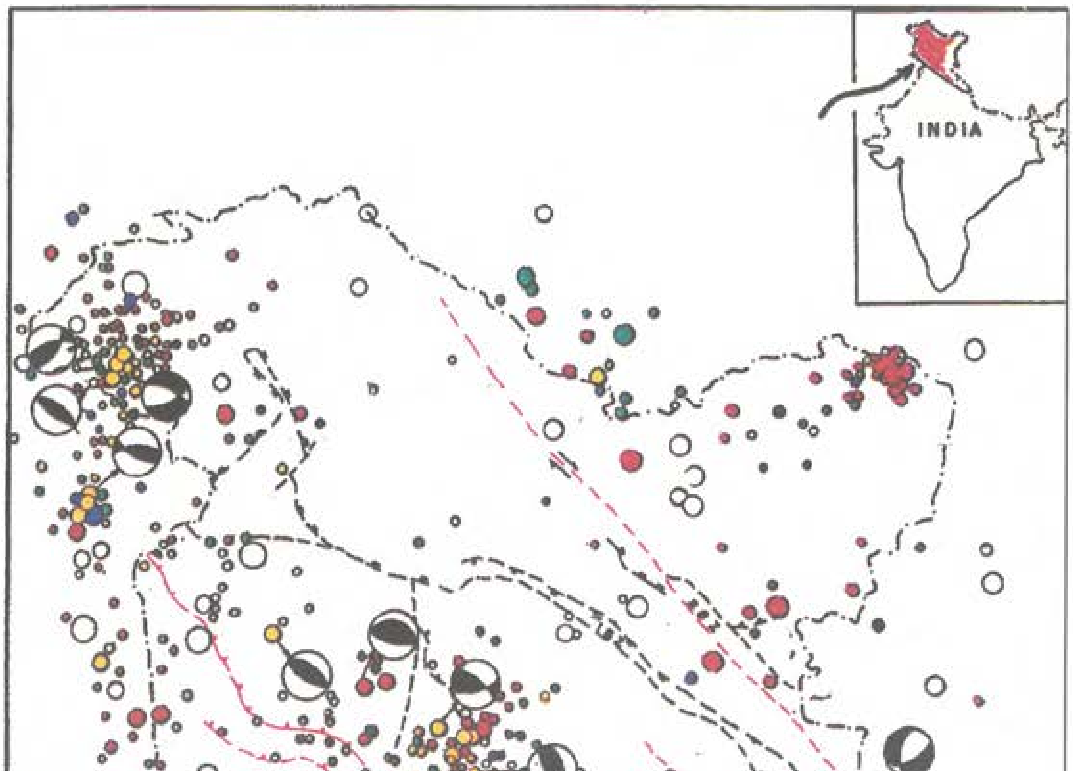
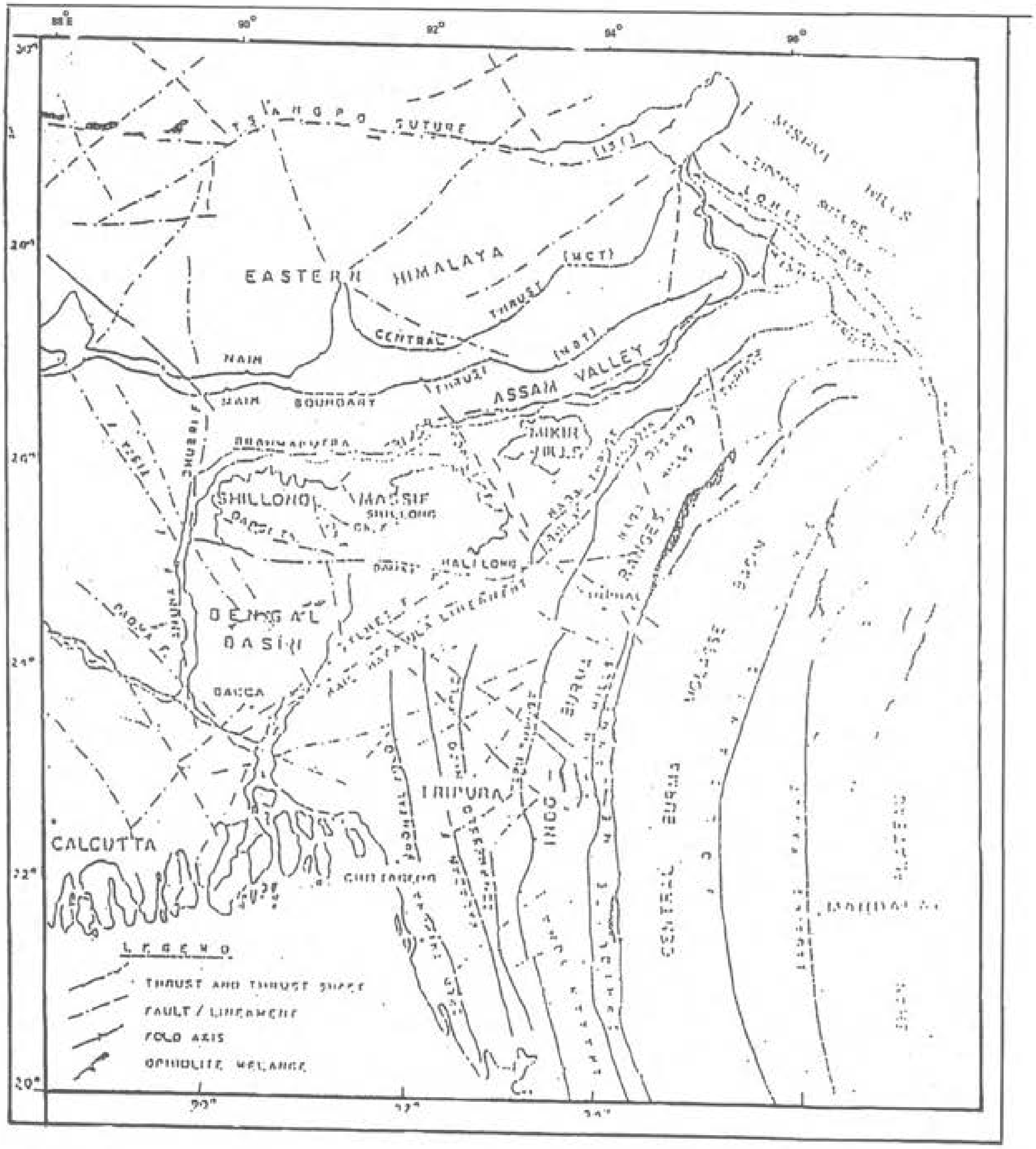
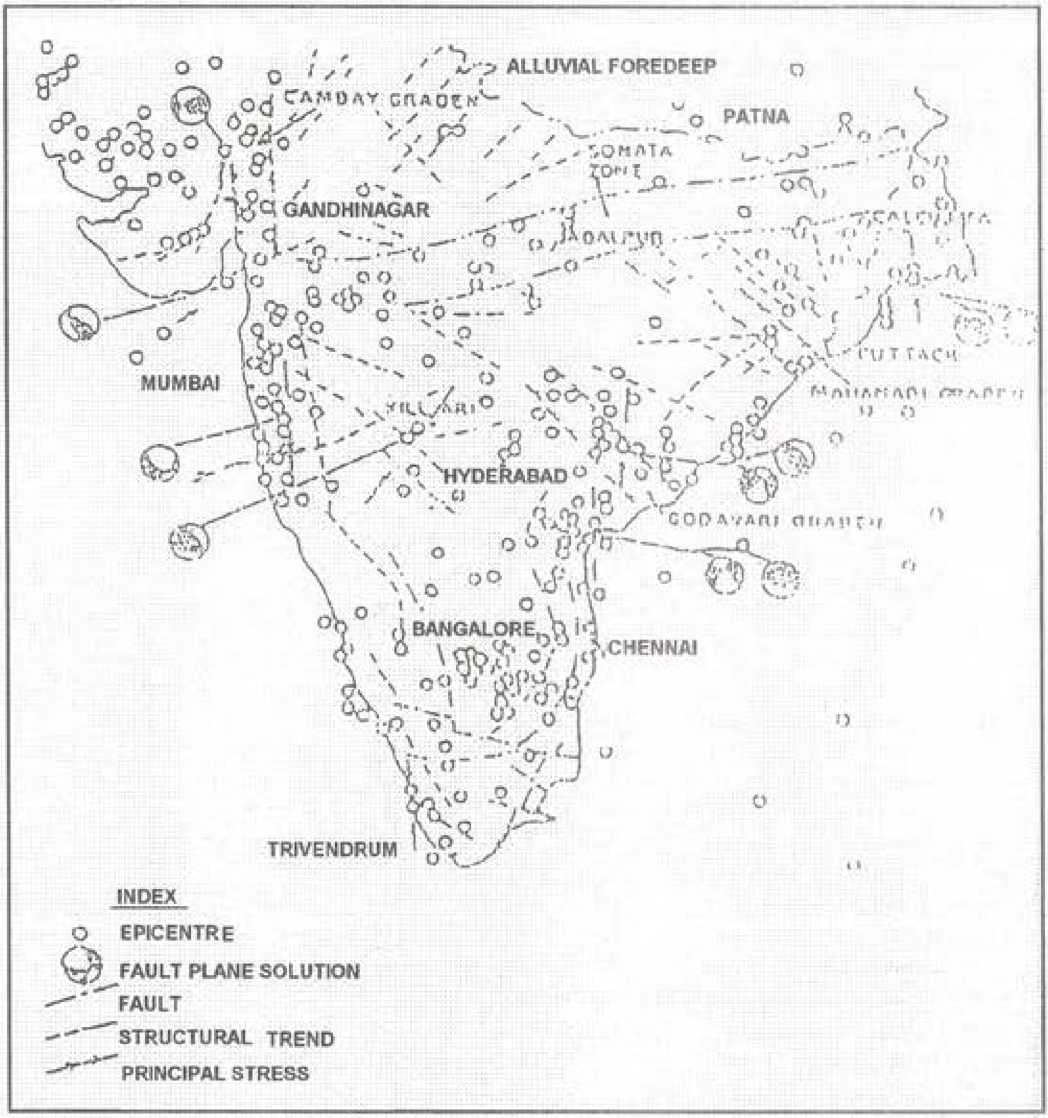


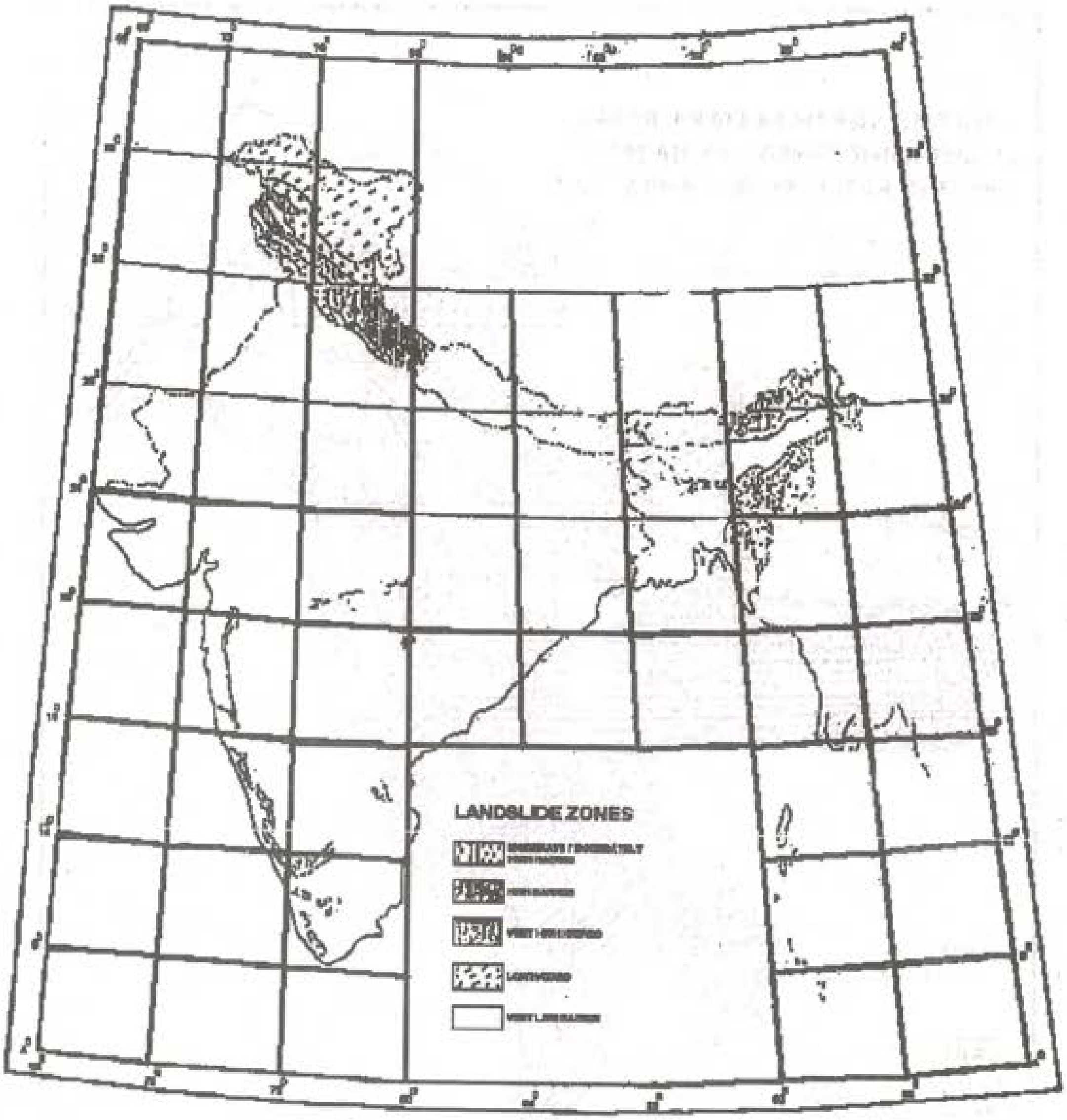
FIG.5. Seismic and neotectonic activity map of north-west Himalaya (after Narula, 1991).



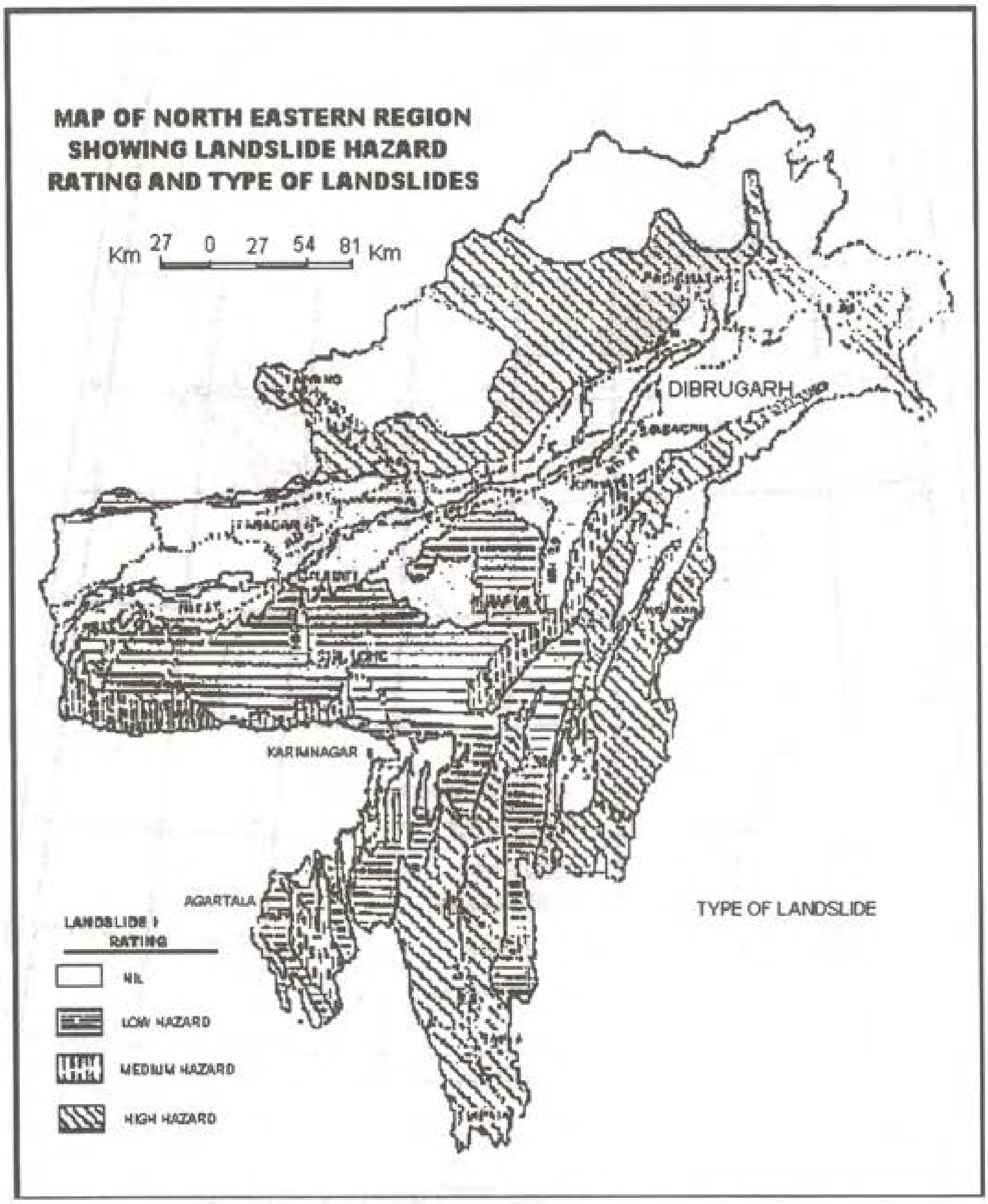
SCISMOTECTONIC MAP OF NE. INDIA

V–26

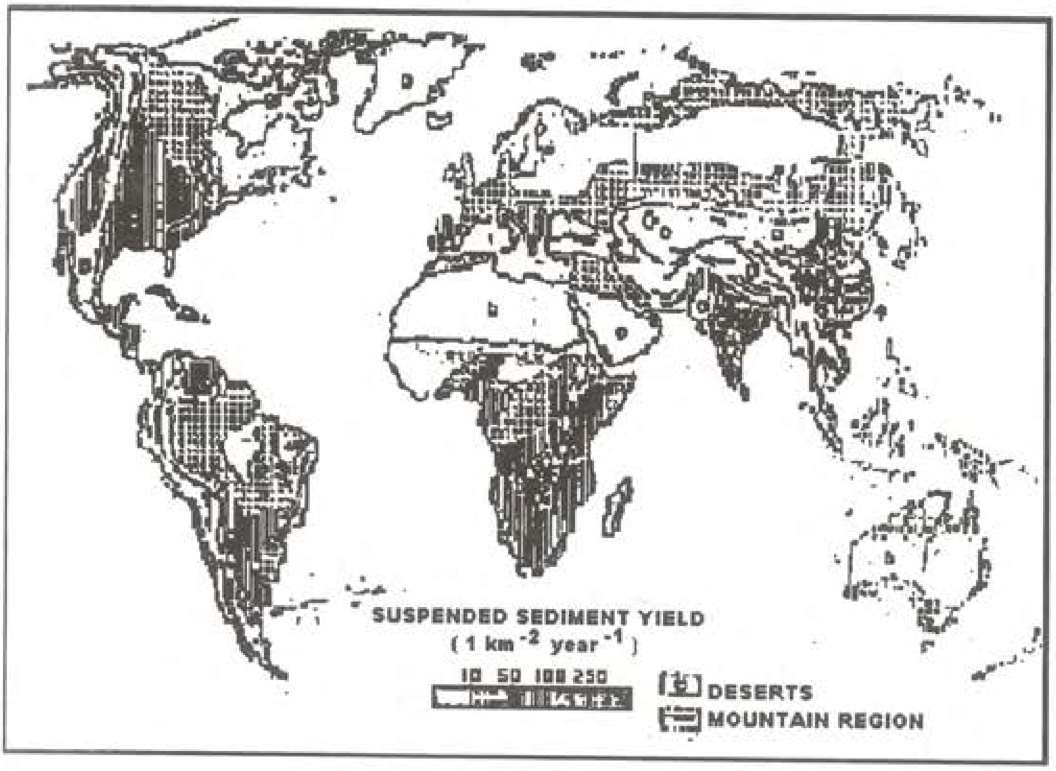

ALLUVIAL FOREDEEP
PATNA
GANDHINAGAR
MUMBAI
HYDERABAD
GODAVARI GRABEN
BANGALORE
CHENNAI
TRIVENDRUM
INDEX
EPICENTRE
FAULT PLANE SOLUTION
FAULT
STRUCTURAL TREND
PRINCIPAL STRESS



LANDSLIDE PRONE REGIONS OF INDIA



MAP OF NORTH EASTERN REGION SHOWING LANDSLIDE HAZARD RATING TYPE OF LANDSLIDES AND AFFECTED HIGHWATS



THE MAP OF GLOBAL SUSPENDED YIELDS PRODUCED BY DEDKOV AND MOZZBERIA(1984) . THE MAPPED SEDIMENT YIELDS RELATE TO DRAINAGE BASINS OF THE ORDER OF 10^4 KM^2 IN NON-MOUNTAINOUS AREAS.

CHAPTER - VI

SILTATION OF RIVERS IN INDIA – REMEDIAL MEASURES, THEIR MERITS, ECONOMIC, LEGAL, ENVIRONMENTAL AND SOCIAL ASPECTS.

1.0 Principal Contributory factors for Siltation in Rivers :

i) The run off volume and peak discharge from the catchment and sub-catchment areas.

ii) High intensity of rain fall even of short duration leads to higher run off and more silt charge.

iii) Much of the siltation in rivers originate from the tributaries from where it is transported into the mother river and deposited elsewhere. Thus, maximum contribution of silt to the river is mainly through rainy tributaries which span the total catchment area.

iv) Quality, quantity and concentration of sediment brought down from the upper reaches of the river along its course depends on the soil in the catchment area, cross section of the river, strength of current etc.

v) In a riverine estuary, the siltation is influenced by the salt water intrusion and location of the salinity wedge. Here Siltation occurs when the flood discharge/strength and the ebb discharge/strength in a certain area of the river are considerably different which results in settlement of suspended sediment.

2.0 Land Erosion and Siltation of Rivers :

When rain fall occurs in excess of infiltration capacity of the soil, the flow of water over soil surface exerts a drag or active force on the soil. If the drag force is sufficiently large, soil particles are dislodged and transported along with the water. This process of transport of soil is retarded and the rate of siltation is kept checked by the presence of grass, weeds, trees and other vegetation on the ground. Soils are more erodable when dry than they are wet. Adequate vegetation in the catchment area reduces soil erosion.

When the land is brought under cultivation, deforestation is carried out and the soil mass is thus exposed to the abrasive action of water and air which results in accelerated erosion of top soil. The total quantity of fertile soil is lost in such a way and siltation caused is very large. To minimize siltation in the Indian rivers, we need to adopt soil conservation measures. Steep slopes need to be divided into terraces or steps thereby preventing the water from attaining high velocities and thus reduce the sheet erosion. Gully erosion can be avoided by constructing small check dams that retard the flow and trap the sediment before entering into the river course.

2.1 Floods and Siltation of Rivers:

Occurrence of floods in any particular part of a river depends upon the degree of precipitation and the water shed characteristics and channel capacity.

Floods result in inundation, erosion of the river bank and also change of the river course itself. One of the major consequences of silting in rivers is the inundation due to inadequate channel capacity at the time of excessive run off which results in overflow of banks. The bank erosion occurring due to floods adversely affects vast stretches of agricultural land due to the rapidly moving current which eat away the easily erodable material of the bank.

3.0 Remedial Measures:

The long term remedial measures to prevent/reduce silting of rivers is through planned watershed management, construction of river training works such as bank protection, spurs, dams, reservoirs etc. Dredging is a remedial measure for desilting in the rivers. When dredging is carried out as a planned activity, the results are quick and visible.

Following are the various aspects related to dredging as a remedial measure for desilting of rivers:

3.1 Definition of Dredging:

Dredging is the process of excavation of all types of soil from below the surface of water by means of mechanical, hydraulic and pneumatic equipment and relocation of the same at the designated site as per the requirement.

Dredging is primarily carried out for development and maintenance of waterways by excavating the soil to the desired depth by means of dredgers. Various types of dredgers such as Trailer Suction Hopper Dredgers, Cutter Suction Dredgers, Grab Dredgers, Bucket Dredgers etc., are used for carrying out dredging operation.

The relocation of the dredged materials depends upon the utility of the same and availability of alternative areas. Sandy material is normally used for the purpose of reclamation of low lying areas and for artificial land development for commercial/recreational use. Alternatively, the dredged material is dumped at designated location in the sea/river.

3.2 Dredging as a Preventive Measure for Flood Control:

Excessive siltation at certain locations in a river results in reduction in the channel capacity and leads to floods in the adjacent areas. Dredging is basically a preventive measure for avoidance of floods by physical removal of soil from the river/reservoir. It is also resorted to for facilitating growing up and maintenance of a channel for navigation.

With the objective of obtaining immediate results, dredging is carried out for desiltation of the river. However, in areas prone to severe floods, desilting of river through dredging operations carried in conjunction with river training works and well planned watershed management aimed at reduction of flood run off would provide a long term solution to the problem. Also, construction of levees or embankments, improvement of reservoir capacity (by desiltation of the same) etc., result in a systematic and planned approach towards flood control and avoidance of hardship to local population.

Since most of the silt in the rivers is brought in by the tributaries, it would be more economical and technically viable if tributaries and nallahs are given due attention in controlling the flow of silt into the rivers. This may be done by adopting suitable desiltation methods in the tributaries. Mechanical methods with land based machinery such as bulldozers and poclains may be adopted during dry season to offload the silted up portions by trucks and also to create suitable silt traps in which future silt deposits could be contained. It is possible that the desilted material could be made use of as construction material or for agricultural use, depending upon the nature of the material dredged. Also, surrounding villages can derive benefits through improved employment opportunities when the above method of desiltation is adopted.

Since all the above Civil Engineering works such as river training works, dredging etc., involve huge expenditure, it is appropriate to carry out model studies before execution of the Project. This is especially required in the case of dredging because the amount spent on the dredging project is huge necessitating a cost benefit analysis with the technical data compiled over the past several years. Thus, before embarking on a major desilting operation in any of the rivers, it is appropriate to consult Hydraulic Engineers from any of the Institutions/Bodies such as IITs/Universities/Water Transport Departments of State Governments etc., and carry out model studies either by means of physical models or by mathematical modeling before arriving at a decision to carry out large dredging operations involving considerable technical and financial risks.

3.3 Dredgers for Desiltation of Rivers:

Desiltation in rivers has to be necessarily carried out by small/medium hydraulic dredgers that are integral floating units consisting of power unit, dredge pump and dredging ladder with excavating device or cutter in one unit which can be launched in one hull section directly into the water body. Most of them are generally equipped with diesel engine as the main power unit.

3.3.1 Portable Cutter Suction Dredgers:

The Portable Cutter Suction Dredgers are most suitable for deployment in the upper reaches of the rivers. These Dredgers need to be designed in such a manner that they safely carry out dredging operations in a riverine environment consisting of fast moving waters and changing bed profile. The Dredger has to be provided with sufficient buoyancy so as to float in the river and carry out the excavating operations.

These dredgers normally weigh between 8 to 25 Tons depending on the equipment fitted and generally the diameter of the discharge pipe is indicative of the dredgers size and output.

The Cutter Suction Dredger consists of a pontoon with a well. At the Aft portion of the pontoon two heavy hollow spud poles are provided and one of these is always lowered into the river bed to keep the dredger in position. A heavy suction ladder is connected to the hull with hinges. A Heavy gantry and a winch are provided to enable accurate lowering/hoisting of the suction ladder. Depending on the designed pumping distance one or two centrifugal dredge pumps are installed in the pump room. Some dredgers are fitted with a submerged pump on the suction ladder. A cutter head is mounted near the entrance of the suction pipe and is mechanically driven by a motor and a shaft or directly by a submerged motor. There are two side anchors connected on either side of the suction ladder which enable the dredger to swing in an arc around the spud pole. The Cutter Suction Dredger can excavate various types of soil and pump a slurry of soil and water mixture through the floating/shore pipeline connected to the dredge pump. Often Portable Cutter Suction Dredgers are designed to work in currents with maximum velocity of 1 Mtr/second. These Cutter Suction Dredgers are not designed to operate in swell conditions because the movement of the pontoon may break the spud poles or damage the hinges of the ladder.

In order to drop the anchors and shift the same after the Dredger advances by certain distance, suitable ancillary equipment such as anchor pontoons and mechanical launches need to be provided to attend to the floating pipeline, shifting of anchors etc. In the case of portable cutter suction dredgers the floating/shore pipe line is normally made of HDPE, since it is light in weight, durable, economical, easy to handle and possesses good wear characteristics.

3.3.2 Jet Dredger:

Jet type dredgers are floating pontoons equipped with a diesel engine driving a jet pump capable of discharging significant quantities of water at a high pressure through a nozzle into the river bed .Thus it dislodges the bed material and brings it into suspension to be carried away in the down stream direction.

Application of jet dredgers is very effective at certain locations such as near floating pontoon jetties when they are grounded due to siltation in the area. When the high pressure jet water impinges on the material the same is dislodged and cleared and enables the pontoon to float freely. Once the suitability of a Jet Dredger is decided, the application is easy and results are quick. Unlike a portable Cutter Suction Dredger, a Jet Dredger does not have a slurry discharge pipe line and the suction pipe on the ladder is replaced by a high pressure water discharge pipe.

3.4 Dredging of Operations :

Wherever the operation with land based equipment is not technically viable, desilting of rivers has to be necessarily carried out by deployment of suitable dredgers such as Portable Cutter Suction Dredgers/Jet dredgers. By deploying a dismountable Cutter Suction Dredger of suitable dredging depth and acceptable draft (which depends on the Least Available Depth of water over the sand bar in the river during the period of dredging operation). The river bed material has to be dredged and pumped ashore in such a way that it is taken out of the sedimentary regime and is not washed back into the river easily. Suitable earthen dykes may be constructed ashore within the reach of the Dredgers' pumping capacity and the silt free water is allowed to return to the regular course. When the moisture contained in the reclamation area comes down after a season or so, the reclamation area may be made available for the use of local community for agricultural/industrial use.

While planning dredging activity, it should be kept in mind that the operations are carried out in an eco-friendly manner and derive social benefits like community farming, promotion of small scale industries and meet the local needs like employment to villagers etc. Care should also be taken to minimize unnecessary exploitation of sand mining which may bring negative effects and at times bring morphological changes in the river and instability of banks because of improper and excess desilting.

Management of desilting operation in a certain portion of the river has often proved to be tedious and at times unproductive. Removal of enormous quantities of silt from the river bed necessitates longer periods of dredger/hydraulic excavator deployment. Often, difficulty is encountered with regard to accessibility of the site to transport a suitable dredger to carry out desilting operations. When dredging operations are carried out in remote areas, proper logistic planning is essential prior to commencement of the project. Apart from mobilizing the ancillary crafts for the dredger, House Boats need to be provided for accommodating the personnel employed on board the dredger. Often, the backlog of silt accumulated in a particular area is so large that the expected project duration for desilting a particular area of a river may even take 4 to 5 years.

4.0 Hydrographic Surveys :

Hydrographic Surveys are necessary for effective project monitoring and to assess the quantity of soil excavated. In the case of river dredging where reshoaling of the dredging area is prevalent, the better way to arrive at the quantity dredged is to measure the same at the shore reclamation site. Once the chart datum of the river at the dredging site is arrived at, accurate sounding charts can be generated by using Echo-sounders and satellite based Position Fixing Systems.

Frequent hydrographic surveys carried along with study of currents and volume discharge in a river would enable assessment of morphological changes occurring in a river and ascertain the reasons for the same. Thereafter model studies by simulation techniques would render solutions to the problem of silting in rivers.

If alternative locations for shore disposal of dredged spoil is not available near the project area under consideration, it may be more appropriate to carry out dredging operations in such seasons that the dredged material can be pumped back into the river at nearby location and the suspended solids are carried away by the fast moving water and the material transformed into suspended solids and get deposited in some other area where the cross-section of the river is larger when compared to the area where siltation has occurred. This methodology is more appropriate in estuarine rivers where desilting operations are to be carried out to facilitate water transport by barges etc.

5.0 Operating Personnel for Dredgers :

Dredging operation is a skilled job because the output of a dredger significantly depends on the knowledge and skills of the operating personnel. Since dredgers are very expensive plant and equipment, it is only appropriate that personnel employed for operation of the dredger are qualified and well trained so that productivity is maximized and the costs are minimized. Over a period of time, it has been observed that the Navigating personnel like Inland Master and Technical personnel (Engine side) trained and certified to work on

Inland Vessels have been found to be suitable to operate these Inland Dredgers. Hence, it is suggested that dredging may be included in the curriculum for training of the above personnel by the various Regional and National Training Centers set up for training of personnel for Inland Vessels and Fishing Vessels.

6.0 Economical and Social aspects of Dredging :

Dredging is an expensive method for excavation of the river bed for desiltation of river and flood control. However, the cost incurred in dredging operation has to be analysed taking into consideration the direct and indirect damage that floods may cause in the adjacent areas. Since floods result in damage to crop, loss of life and property, disruption of communication systems etc., and result in expenditure on flood relief, rehabilitation measures, restoration of communication systems and costly repairs to roads, bridges, railway lines etc., it is appropriate to compare the cost of dredging with the direct and indirect benefits for the population living on the river banks.

The cost of dredging per cubic meter of solid material employing a Portable Cutter Dredger and pumping through a distance of 1000mtrs. would range from Rs.50/- to Rs.90/- depending on the type of soil. The above cost does not include the cost of mobilisation and demobilszation of equipment by the Contractor. Certain materials like silt, mud and loose sand are easily dredgeable than compacted sand and gravel. The cost per cubic meter of quantity dredged depends on the abrasiveness of the soil. Abrasive soils like coarse sand result in wear-down of the dredging equipment like dredge pumps, cutter head etc. and result in increased operational costs. A well planned dredging project with approximate dredging technology would result in significant cost reduction.

Though dredging is a very expensive activity, the same has to be viewed from the socio-economical benefits expected to result by execution of the dredging project. The sand bars prevalent in various Inland Waterways of India impede the surface navigation of barges along the rivers.

By implementing the above suggested measures, we can derive significant social benefits through improvement in the business and commerce in various Towns and Villages lying along the river banks. Similarly reducing the cost of dredging through above suggested subsidies would reduce the cost of dredging as a preventive measure for flood control and thus reap social benefits to the population living near the flood-prone areas on the banks of the rivers.

7.0 Environmental Effects :

When rivers flow for longer duration, they sustain life both to plant and animal due to natural phenomenon. The animals and plants die and settle at the bottom to be decomposed by bacteria. During this process, the decaying biomass liberates gasses and substances like Hydrogen Sulphide, methane and other toxic wastes. These generally lie trapped in the top layers of sediments. When these layers are disturbed during dredging and affect the life supporting pattern of the water above, the turbidity added to the water during dredging reduces the penetration of sunlight which in turn reduces photo syntheses and shrinks the life supporting bio pyramid which causes further degradation of aqua life. The disturbing of sediments also causes these sediments to transports to nearby water sheds and deposit. Thus, aquatic life gets affected due to dredging up streams.

Dredging operations are likely to result in oil pollution because Diesel Engines that drive various machinery/equipment on board a dredger consume large quantities of fuel oil. The dirty oil in the bilges if pumped out into the riverine/marine environment will damage the eco-system. In the case of portable dredgers, such dirty fuel/hydraulic oils have to be collected in drums and sent ashore. Oil pollution during dredging operation in delicate aquatic environment is likely to cause long term damages to the eco-system. Before a dredging project is taken up, the Pollution Control Board of the State or any other concerned Governmental Body should ensure that the dredge operator does not pollute the aquatic environment and the dredger is equipped with chemical dispersants and the personnel operating the dredger are conversant with the emergency Action Plan in case of oil pollution.

In the light of the above facts, it is prudent to carry out Environmental Impact Assessment for dredging projects and this is a necessity in the case of large dredging projects which spread over several years. However, a rational view has to be taken by weighing the social benefits through enhanced economic activity, additional employment opportunities on one side and the preventive measures planned to protect the environment.

8.0 Legal Aspects :

In India, there is no Act as yet directly pertaining to dredging. However legislations promulgated by the Central and various State Governments pertaining to Environmental protection, Pollution Laws, conservancy of wetlands, and methodology laid out in special activities like Ganga Action Plan for clear water are generally the basis for interpretations and application of legal aspects in dredging. With the environmental movements getting an impetus through active participation by NGOs, there is often a conflict of interest between the dredging Contractor/Employer and the local groups. In India, it is the responsibility of the Employer to seek environmental and legal clearances if any for commencement/execution of a dredging project.

In so far as dredging in the rivers for desiltation of the same is concerned, the best way to manage is to take the local groups and NGOs into confidence and carry out the dredging activity with minimal damage if any to the eco-system in the dredging/disposal site.

In so far as the legal aspects of dredging, what is of concern in the Indian scenario is the frequent occurrence of arbitration proceedings especially between Employers in the Government Sector and Private Contractors. Normally the Chief Engineer of the Project is designated to resolve disputes between the Employer and the Contractor. Otherwise if mentioned in the Agreement, the Arbitration and Reconciliation Act of 1996 becomes applicable. To overcome legal problems during execution of a dredging project and to avoid payment towards extra claims by the Contractor, it is prudent on the part of the Employer, especially in the Government sector to arrange for drafting/vetting of the tender document/agreement by technical/legal experts so as to ensure smooth completion of dredging project and control the costs through avoidance of cost – time over run.

9.0 Conclusion :

Thus it is recommended that dredging for desilting of Indian Rivers may be adopted in exceptional circumstances to improve the flood mitigation and navigation.

CHAPTER – VII

SPECIAL PROBLEMS OF SILTATION OF RIVERS IN INDIA

1.0 River Siltation in Krishna River Vis-à-vis Problem of Power Generation by Srisailam Hydroelectric Project.

Srisailam and Nagarjunasagar reservoirs, constructed one downstream of the other on Krishna river, form two of the largest man-made lakes in India with a combined gross storage of over 20,000 M.cu.m. Such a system of two large reservoirs in cascade in close proximity to each other in the same river is unique, which facilitated development of hydel power in the conventional storage mode as well as in reverse pump operation mode. Srisailam Left Bank Hydro-Electric Project has been formulated to generate hydro-power using available water storage from Srisailam reservoir and additional hydro power generation with pumping of Nagarjunasagar reservoir water back to the Srisailam reservoir, subject to availability of off-peak thermal energy in the Andhra Pradesh Power Grid for the pumping operation. The tail water pond for pump operation is the Nagarjunasagar reservoir with a fetch distance of approximately 100 km.

During the lean flow season from March to July, the water pool in Krishna river for pump operation poses problem of discontinuity of water pool/flow at places, thus hampering pump mode storage for additional power generation by the Srisailam Hydro-electric Project.

1.1 Satellite based Study of Krishna River Reach from Srisailam Dam to Nagarjunasagar Dam.

The reason for the discontinuities in water pool at several places for the 13.5 km. river reach downstream of the Srisailam dam, based on a study by NRSA using multi-date satellite data pertaining to highest to lowest water levels in Krishna river reach for the year 1994 – 1995, is found to be the presence of stream outfall deposits brought out by a number of hill streams outfalling into Krishna river, bringing rain wash-out deposits like rock boulders, pebbles, moorums and coarse sands every year during monsoon season and thus create fan shaped deposits in the river bed (Figure 1). There is remarkable correspondence between location and areal extent of these stream outfall deposits with the discontinuities in tail water pool as revealed from the satellite image very distinctly (Figure 2).

The location and size of discontinuities in flow and stream outfall deposits are estimated corresponding to different elevation levels of Nagarjunasagar reservoir (Table 7.1). It is found that, between the period from March' 95 to June' 95 areal extent of each of these outfall deposits remains more or less same, although reservoir water levels come down from 158.31 metres to 151.85 metres (Table 7.2). This indicates that, these outfall deposits remain above the river water levels downstream of Srisailam dam during the lean flow period causing breaks in water pool. Controlling/maintaining of Nagarjunasagar reservoir to certain desire water level (s) may not serve the purpose of avoiding discontinuities in tail water pool of Nagarjunasagar reservoir, as initially perceived.

Table –7.1

Observed Breaks in Tail Water Pool of Nagarjunasagar Reservoir at Different Elevation Levels, Derived from Multi-date Satellite Data.

Date	Water level in Nagarjunasagar Reservoir		Break in Water Pool	Distance from Srisailam Dam (Km)	Length of Waterpool Break (m)
	(m)	(ft)			
19-Mar-95	158.31	519.40	B1	1.8	445
02-May-95	153.41	503.30	B1	1.6	650
			B2	7.5	120
24-May-95	152.86	501.50	B1	1.6	650
			B2	7.5	190
			B3	11.75	185
15-Jun-95	151.85	498.20	B1	1.6	735
			B2	7.5	205
			B3	11.5	310
			B4	13.5	180

Table –7.2

Estimated Areal Extent of Stream Outfall Deposits in Krishna River D/S of Srisailam Dam, Derived from Multi-Date Satellite Data.

Date	Nagarjunasagar Reservoir Water Level		Areal extent of Stream Outfall deposit (sq. metre)			
	(m)	(ft)	D1	D2	D3	D4
03-Feb-95	168.58	553.1	110,000	257,000	-	-
19-Mar-95	158.31	519.4	227,000	473,000	102,000	231,000
10-Apr-95*	154.87	508.1	212,000	418,000	94,000	231,000
02-May-95	153.41	503.3	227,000	503,000	116,000	312,000
24-May-95	152.86	501.5	246,000	516,000	143,000	312,000
15-Jun-95	151.85	498.2	246,000	532,000	145,000	312,000

- Due to water release from Srisailam Dam on 10-Apr-95, the areal extent of stream outfall deposits got reduced on that day.

Thus the satellite based study has identified conclusively the presence of 4 major stream outfall deposits in the Krishna river reach of 13.5 km. from the Srisailam dam as the principal contributing factor of discontinuity in water pool which takes place when the water level of Nagarjunasagar reservoir is low between March to June (Table 7.3). The precise location of these deposits as well as their size in terms of mapping units and area estimation is made in the study.

Table 7.3

Identified Stream Outfall Deposits in Krishna River Downstream of Srisailam Dam derived from Satellite Data

Stream Outfall Deposit	Distance (Km) from Srisailam Dam	Contributing Stream
D1	1.7	Karikela vagu
D2	4.35	Nekkanti vagu
D3	7.25	Varrapati Kalava
D4	13.2	Mamidrevu vagu

1.2 Remedial Measures

1.2.1 Selective Dredging

There is no other way, except, selective dredging of these stream outfall deposits. In fact, a mechanical dredging operation in limited scale is already in progress in Krishna river near the tail race exit point to facilitate immediately the reversible pump mode of operation. Since river gorge consists of very steep hills with rock outcrops on both the banks, a fully mechanised dredging unit can not be taken to the river sites at several places. Instead, dredging unit is being assembled in-situ. Similar exercise is recommended to be taken up in all the four identified deposit points for dredging operation. Satellite data derived maps and estimation will be handy in planning the dredging scheme.

1.2.2 Disposal of dredged materials

Disposal of dredged materials to available safe places is a problem since dredged materials need to be removed and be disposed far away from the river banks so as not to re-enter the river bed as rain-wash out materials in future. Disposable safe places around the hill gorges in Srisailam are available; only removing the materials far away is a costly proposition. For long term benefit of sustainable and economic return from the Srisailam, Hydro-Electric Project, this immediate investment in dredging and disposal will be useful, of which Andhra Pradesh Power Generation Corporation Limited (APGENCO) is seriously seized of this immediate and urgent solution to enable the project to realise fullest benefit of hydro-power generation.

1.2.3 Construction of Gabion type Check Dams in the Hill Streams

Selective dredging of river bed at places, to be appropriately decided by the hydrographic river survey or by aerial/satellite based remote sensing technique, is essentially a short term measure. For long-term measures, watershed management of the contributing streams needs to be taken up on a sustainable basis.

The satellite based study has identified four major hill streams, namely, Karikela vagu, Nekkanti vagu and Varrapati Kalava on the right bank and Manidrevu vagu on the left bank contributing to the outfall deposits in Krishna river bed within 13.5 km. distance from the Srisailam dam which is causing discontinuity in water pool in Krishna river. Beyond 13.5 km. continuity in water pool exits even in lowest water level of Nagarjunasagar reservoir (Figure 3).

Watershed management in terms of structural control of these hill streams to prevent rain wash-out materials to find ways as deposits in the Krishna river is recommended by the study. Gabion type check dams, which are permeable to rain water flow and at the same time these hold back the rain wash-out materials, are suggested to be constructed in the eight watersheds (Table 7.4) in this 15 km. river reach for permanent solution of Krishna river silt depositional problem.

Table 7.4

Identified Hill Streams & their Watershed Areas Contributing to Outfall Deposits in Krishna River D/S of Srisailam Dam

Sl.No	Stream Name	Watershed Area (Hectares)
1	Karikela Vagu	4,880
2	Nekkanti Vagu	10,737
3	Varrapati Kalava	1,543
4	Jalpendra Vagu	407
5	Tangalrevu Penta Vagu	716
6	Mamidrevu Vagu	4,361
7	Kurthi Penta Vagu	1,571
8	Moti Vagu	1,230

2.0 Bank Erosion in Majuli Island in Brahmaputra

2.1 Cause :

The braided channel of the Brahmaputra river in Assam is characterised by numerous sand bars and islands. `Majuli', the world's largest river island is situated to the north of Jorhat and at the confluence of the Subansiri river with the Brahmaputra river. The island (latitude 26^0 32' to 27^0 10' N and longitude 93^0 30' to 94^0 35'E) covers an extent of about 900 sq.km. with a total population of 1.3 lakhs as per the 1991 Census of India. Administratively, the island forms one of the sub-divisions of the Jorhat district. The people living in the island are primarily agriculturalists. Weaving, fishing and bamboo based utility making are some of the other activities by which people make their earning for daily livelihood. Kamalabari is the major township of the island, connected by a criss-cross road network to reach almost all the places in the island. Figure 4 shows the location of the Majuli island in the Brahmaputra river between Jorhat on the southern bank and North Lakhimpur on the northern bank in Assam.

The island is facing severe erosion of bank line by both the rivers, Brahmaputra and Subansiri, during flood season every year. The erosion is more conspicuous from the southern side of the island, caused by the Brahmaputra river. During the south-west monsoon season, a large part of the island is inundated by the spill waters of the Subansiri and the Brahmaputra rivers when they are in high spate. Vast areas remain under sheet of flood water with an average depth of 2 to 3 metres over a period of 10 to 15 days. This badly hits the economy of the island as it is essentially dependent on agriculture.

As floods in the Brahmaputra river are accompanied by disastrous erosion of banks, it is a common sight at the Majuli island to witness 30 to 40 metres strip of land being eroded away within a few hours during flood. The rate of erosion depends on various factors such as severity of attack, angle of incidence, river water turbulance, granulometric and other physiochemical characteristics of the bank soils and their stratification.

According to the 1971 Census of India, the geographical area of the island (including some chars or chaparis) was 924.60 sq.km, as against its earlier area extent of 1246 sq.km. during 1950, reported in revenue record. As per the 1991 census of India,the island has 244 villages, out of which 35 villages have been eroded by the two rivers. Prior to the great earthquake of 1950, bank erosion in Majuli island was not so acute. It has become more serious after the flood of 1954, and since then, bank erosion has become a continuous feature on both sides of the island.

2.2 Identification of extent of Bank Erosion from Satellite Observation:

Remote Sensing technique is a handy tool to identify vulnerable reaches in a river. Following characteristics are determined with the help of satellite data.

(i) Assessment of the land affected by the annual flood events

(ii) Mapping changes in river channel configuration of Brahmaputra river and Subansiri river which shapes and re-shapes Majuli island year after year

(iii) Delineate the extent of the areas of bank erosion and to work out priority areas for immediate protection measures are difficult tasks in this mostly unapproachable river island, but most vital to protect agriculture, infrastructure and people living in this area.

Landsat satellite data of 1986-88 time period have been used earlier to know the area-wise distribution of landuse in Majuli island (Table 7.5). This, however, needs review with latest high resolution satellite data, since much changes in landuse must have taken place in the intervening period.

Table 7.5

Landuse distribution in Majuli island derived

from Satellite data of 1986-1988

S.No.	Landuse Class	Area in Hectare
01.	Net Area Sown	30,584
02.	Current Fallow Land	4,647
03.	Lands belong to non-agricultural uses	75,943
04.	Pastures & Grazing Land	544
05.	Cultivable waste land	4,621
06.	Barren/uncultivable land	7,461
07.	Miscellaneous Trees	80
08.	Forest	Nil

Net area sown includes both kharif and rabi crops grown in this island. Before the construction of the embankments, cultivation of kharif crops was rather uncertain. In recent times, construction of embankments has protected the kharif crops to a large extent. However, due to annual occurance of flood, farmers are more dependent on rabi crops as it is more successful in this island. Paddy is extensively cultivated. In addition, maize, other cereals, black gram, cotton, jute, castor, mustard, sugarcane, vegetable etc. are grown. Uncultivable land includes high reed jungles interspersed with swamps/beels. Pastures & grazing land and cultivable wasteland include large stretches of rich fodder grass.

Erosion problem in Majuli island has been studied by various agencies from time to time. The study group, constituted by the Govt.of India in 1964 to assess the erosion problem of Brahmaputra river, had carried out investigation over the changes in bank line for the period from 1923 to 1954. The study concluded that the northern bank of the Brahmaputra river has undergone erosion for a length of about 230 km. between Kobo (downstream of Pashighat) and Dubri.

In a latest study (1996), commissioned by the Brahmaputra Board, using multi-date satellite data for the years - 1987, 1988, 1992, 1993, 1994, maps of river configuration and areas affected by bank line erosion in Majuli island were prepared. The maps prepared on 1:50,000 scale contain information like river bank line, active stream course, sand bar, stabilised chars, embankment and river bank line erosion zones. These maps prepared on common scale and base map datum provide change detection from year to year with respect to bank line changes, erosion status, performance of the embankments and their breaches. Keeping Survey of India topographic maps of the period 1969-1972 on 1:50,000 as a base map datum for this study, the total loss of land in the island during 1969-1994 was estimated to be 50.27 sq.km. (Table 7.6).

Table 7.6

Area Lost due to Bank Erosion in Majuli Island from 1969 to 1994.

		Villages Eroded	Loss of Land (sq.km)
	Bank line Erosion due to Brahmaputra river	A.Kathanigaon,Ujanigajeragaon,Sounal, Kacharigaon	22.63
		B. Lachangaon	3.15
		C. Kumargan,Baemari	7.75
		Salmaragaon, Bechmaramirigaon	0.75
		Kaniagaon, Batiamarigaon, Majavaon	7.45
		F Biringabari, Khorapargaon	4.63
		Sub total	46.36
	Erosion due to Subansiri river.	G Kumbarbari	1.50
		H Chitadarchapari	0.75
		I Chitadashchapari	0.64
		J West Borabari	0.62
		K Kaibartagaon	0.42
		Subtotal	3.91
		Grand Total (46.36 + 3.91)	50.27

Out of the 5.43 percent loss of land in the Majuli island between 1971 (as per 1971 census, area of Majuli island was 924.60 sq.km) and 1994 (satellite data based estimate), bank line erosion by Subansiri river accounts for 0.42 percent and by Brahmaputra river accounts for the balance of 5.01 percent. This confirms that the erosion threat to the Majuli island from the river Brahmaputra is extremely high compared to Subansiri river.

Analysis of multi-date satellite data supplemented with ground observation reveals that the island is facing bank line erosion which can be classified into following three categories (Table 7.7). The Island is experiencing predominantly B and C type of erosion spread over a large area.

Table 7.7

Categories of Bank Erosion in Majuli Island.

Erosion Category	Criteria	Location
A. Major erosion affecting large area	loss of land > 10 sq.km	Kothnigaon, Ujanigaon, Sounal Kacharigaon
B. moderate erosion affecting certain areas along bank line	loss of land between 1 to 10 sq. km.	Lachangaon, Kumargaon, Barmari, Kamiagaon, Batiamarigaon, Khoraparagaon, Kumarbari
C. minimum erosion at isolated sites.	Loss of land < 1 sq.km.	Salmaragaon, Bechmara, Mirigaon, Chitadarchapari Chitadashchapari, Borbari, Kaibartgaon

2.3 Anti - Erosion Measures

Protection of island from flood and bank erosion through flood control and river training works like embankment, spur, bank pitching etc. are the only way to minimise their effects over a period of time. In fact, construction of embankments is a most popular measure adopted in the Majuli island to avoid flood water spilling over lands. Upto the end of the 7^{th} Five Year Plan, a total length of 940.57 km. of embankment was constructed along both banks of the island in different reaches.

Another possible method would be river channel improvement by improving the flood water carrying capacity of the existing channels around the island. The method involves dredging of channels and construction of cutoffs. The method is expensive and periodic maintenance is seldom possible as the river channels have the tendency to revert to its original form after some time.

Diversion of channel is an effective way of mitigating the damage, caused by the turbulent river flow at the bank. Satelite based study recommended to divert a part of the flow of Chumiamari channel to the main course of Brahmaputra river.

To save southern side of the Majuli island from erosion, partial diversion of flow can be planned by constructing deflecting spurs near Aphulamukh Chapari village.

Other bank protection measures such as surface and bottom deflectors, bank rivettment, raising/strengthening of the PWD roads can be taken up. In order to plan and implement river training works for protection of banks from erosion, model studies will have to be carried out with the help of latest river configuration to be derived from satellite images.

3.0 Bank Erosion of River Brahmaputra

3.1 Cause

The Brahmaputra river is one of the largest rivers in the world and carries more than 30% of the total water resource in India. The Brahmaputra valley in Assam is a tectono-sedimentary basin, 720 km long and 80 to 90 km wide, underlain by recent alluvium, approximately 200-300 m thick. The flood-plain of the Brahmaputra exhibits an array of alluvial features including natural levees, point bars, meander-scrolls, ox-bow lakes, channel bars and flood basins, etc. The flow channels of the river are characterized by rapid aggradation, dramatic channel shifts and excessive bank line recession. Because of the natural levee of the Brahmaputra, several tributaries in their lower reaches tend to flow parallel to the mainstream until they find some opening to traverse it. This has resulted in the formation of swamps along the lower parts of tributaries. In the foothill region, the sudden change in gradient of the tributary rivers has led to the deposition of coarse alluvial materials in large coalescing alluvial fans and braided channels.

The tributaries on the north come down with steep slopes bringing heavy silt charge and its impact causes the river to shift southwards. The tributaries on the south have flatter slopes and the lateral shift of the river results in shifting of the confluence of the southern tributaries. The tributaries flowing through Sikkim and North Bengal have steep slopes and bring down large quantity of the silt with high velocity, resulting in aggradation of river beds, erosion of banks and changing of the river course. Deforestation, cutting of hillside for developmental works like roads and shifting cultivation cause further problem by way of soil erosion and quick runoff. The heavy silt load results in cross channels and formation of shoals and bars, braiding of rivers and erosion of banks. However, the excessive sediment load which the Brahmaputra carries is mainly due to the frequent seismic disturbances of low magnitude besides the disastrous earthquakes that occurred from time to time in the north-eastern region which geographically is most unstable part of India.

The channel behaviour and configuration of the Brahmaputra river undergoes dramatic changes in response to variation in flow regime and pattern of sediment transport in the river. With the onset of the flood season, sediment transport in Brahmaputra increases, the thalweg starts to change position and the geometry and location of bars change. As the flow begins to recede, deposition over the bed takes place in the form of bars and islands. The river then flows in several sinuous channels in between these sand bars. With the onset of the next flood season, the sequence of events is repeated.

3.2 Quantification of Eroded Banks in Brahmaputra River from Satellite Observation

In order to study the erosion problem and its impact, it is important to have the latest river configuration and comparison of active river channel flow at different times besides other hydraulic and hydrological data. The satellite technology has tremendous potential in providing river configuration map of Brahmaputra river right from Sadiya to Dhubri at a single shot. Further, it can provide a repetitive coverage so that the changes that have taken place over a period of time in the river course can be studied. Result of the study of river reach of Brahmaputra from Taliyagaon to Rajamayang hills (Figure 5.) using multi-date satellite digital data of post-flood period of 1990, 1994 and 1998 presents the following observations.

* During the period 1990-1994, it is observed that erosion has taken place at Garubandha, Baralimarigaon, Bartal Dalaigaon, Taliyagaon, Singri, shyampuri and Cherangchopa. Maximum erosion on the left bank is about 1.8 Kms at Garubanda during this period.
* During the period 1994-1998, it is observed that erosion has taken place at Garubandha, Bhakajari, Baralimarigaon, Barkur, Taliyagaon, Singri, Shyampuri and Cherangchopa. Maximum erosion on the left bank is about 2.1 Km at Baralimarigaon.
* The maximum extent of erosion is observed near Garubandha on the left bank, which is about 2.16 km and near Erabari on the right bank which is about 2.12 km. (Figure 6.)

The maximum eroded area is about 1540 ha near Garubandha. The total area eroded in this river reach during 1990-1998 time period is estimated to be about 6078 ha.

Table 7.8

Quantification of eroded bank of Brahmaputra river from satellite observation of 1990, 1994 and 1998.

Code	Place / location	Geographic Location	Eroded area (hA)	Eroded Bank Line (km)	Number of villages eroded
E1	Left Bank Garubandha	92° 05' 00"E 26° 17' 26"N	1540	2.16	6
E2	Left Bank Bhakajari	92° 08' 07"E 26° 19' 05"N	203	0.9	2
E3	Left Bank Baralimarigaon	92° 09' 53"E 26° 21'05"N	769	1.5	9

E4	Left Bank Barkur	92° 16' 18" E 26° 25' 29" N	649	1.4	4
E5	Left Bank Bartal Dalaigaon	92° 23' 42" E 26° 27/' 08"N	498	0.72	4
E6	Left Bank	-	124	0.51	-
E7	Left Bank	-	35	0.27	-
E8	Left Bank	-	14	0.19	-
E9	Left Bank	-	18	0.43	-
E10	Left Bank	-	36	0.39	-
E11	Right Bank Taliyagaon	92° 34' 41" E 26° 38' 16" N	741	1.39	3
E12	Right Bank Singri	92° 29' 01" E 26° 36' 36" N	895	2.12	8
E13	Right Bank Shyampuri	-	306	0.95	-
E13	Right Bank	-	21	0.25	-
E15	Right Bank Cherangchopa	-	229	1.51	-

Table 7.9

Quantification of bank line deposition in Brahmaputra river observation of 1990, 1994 and 1998

Code	Deposition exent (km)	Deposited Area (ha)	Place location in Figure 2
D1	0.85	95	Left Bank
D2	0.31	68	Left Bank
D3	0.56	152	Right Bank
D4	0.45	66	Right Bank
D5	0.44	72	Right Bank
D6	0.49	42	Right Bank
D7	0.37	48	Right Bank
D8	0.26	39	Right Bank
D9	0.39	24	Right Bank
D10	1.00	147	Right Bank
D11	1.52	465	Right Bank

3.3 Shift in Active River Flow Channel

The main active river flow channels of Brahmaputra river in this reach are interpreted from the satellite data of 1990 and 1998 time period and compared. Shift in active river flow channels are:

* At Rajamayang Hill, the main active river flow channel has been seen to be existing on northern side as well as on southern side during 1990, whereas it is confined towards southern side during 1998.
* At Garubanda, the braiding channel of the river exists in 1990 aswell as in 1998.
* At Baralimarigaon, braiding of the flow channel and active channel flow are observed on northern bank as well as on southern bank in 1990. During1998, braiding of active channel has not been observed and the main channel flow of the river is confined to southern bank only.
* At Barkur, it is observed from 1998 satellite data that active flow channel has been formed towards southern bank which does not exist in 1990.
* At Dhing, the braiding is found to be minimized and main active channel flow is concentrated at the middle of river section.

4.0 Flood / Drainage Congestion in Yamuna River near Delhi

4.1 September 1978 Unprecedented Flood

Regular and recurrent floods in many river basins in the country continue to cause human misery. With the ever increasing population and the consequent encroachment of low-lying areas along the rivers in their flood-plains, the problem is getting acute.

The flood of 1978, in the Yamuna river basin was one of the worst during the last 50 years. The September 1978 flood in the Yamuna was so devastating that, wide-spread breaches in the embankments occurred upstream of Delhi. It submerged about 1813 sq.km., of agricultural land (1,182 sq.km in Haryana, 481 sq.km in Uttar Pradesh and 43 sq.km in Delhi) and caused extensive suffering to half a million population by damaging the entire kharif crop in the affected areas. It also caused appreciable damage to the urban areas in Delhi.

The flood-spill from Yamuna river submerges mostly agricultural areas in Haryana and Uttar Pradesh. The districts likely to be affected in Uttar Pradesh are Saharanpur, Muzaffarnagar, Meerut and Bulandshahar in the upper reaches and Banda and Allahabad in the lower reaches. The districts likely to be affected in Haryana are Karnal, Sonepat, Faridabad, Gurgaon, Kurukshetra and Rohtak.

Delhi, which lies on the banks of the Yamuna river, despite protection against flood-spills by embankments, faces the threat of flood. A significant volume of the flood discharge of the river Sahibi enters Delhi territory through Najafgarh drain which outfalls in the river Yamuna. The problem of flood in the Sahibi river is mainly due to changing course of the river in Haryana. In September 1978, an unprecedented flood occurred in Sahibi river near Delhi due to intense and concentric rainfall in its catchment. Shahibi river flood also coincided with flood inYamuna river which posed serious flood / drainage congestion for the National Capital Region (NCR) of Delhi. The loss estimated in September 1978 flood alone was 10 crores besides loss of 14 human lives.

Yamuna river forms the boundary between Uttar Pradesh and Haryana and, therefore, any flood control work by one State is likely to have repercussion in the other State. Since Delhi also lies in the vulnerable reach of the Yamuna river, surrounded by the States of the Haryana and the Uttar Pradesh, any flood control measures taken up in these two States have to be examined and coordinated keeping in view its consequent effect in Delhi.

The flood protection measures adopted so far by the States in the Yamuna basin, namely, Haryana, Uttar Pradesh, Rajasthan and Delhi have been confined to construction of embankments, improvement of channels and anti-erosion works. There is a proposal to construct three storage dams at Lakhwar, Kishau and Renuka in the upper reaches of the Yamuna and its tributaries, which would afford incidental benefit of flood moderation mainly in upper reaches of the Yamuna river. In reality, flood problem inYamuna river is confined to its middle reach from Tajewala to Okhla. Apart from the problem of overbank flood-spills, the river has been frequently attacking the banks on Haryana side and Uttar Pradesh side. The river has been causing considerable flood inundation as well as bank erosion in Delhi through which it passes.

4.2 Morphology of Yamuna River from Satellite Observation

Keeping the above requirement in view, a satellite based study was undertaken in 1999 jointly by NRSA and CWC for the middle reach of Yamuna river from Tajewala to Okhla. In this reach, river covers about 246 km.

The study dealt with (i) morphology of the river reach, (ii) flood inundation, (iii) landuse-landcover adjoining the river reach, (iv) river bank erosion and (v) flood risk zones using satellite digital data of the dates as shown in Table 7.10.

Table 7.10
Satellite Overpass dates and Flood Peak Dates used in Yamuna River Study.

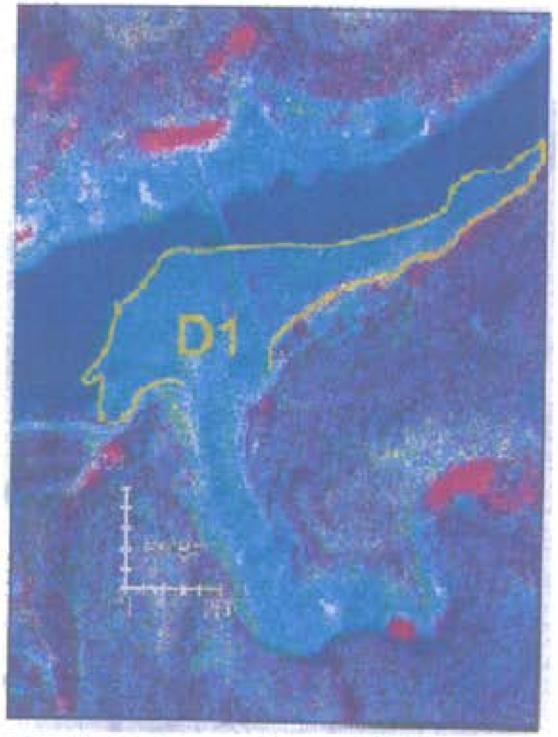
S.No	Date of Flood Peak in river Yamuna at Tajewala	Date of Satellite Overpass over Yamuna	Highest Water Level (metre) in river Yamuna recorded at Delhi bridge
1	27/09/1988	30/09/1988	206.92
2	30/08/1989	31/08/1989	205.67
3	19/08/1992	30/08/1992	205.40
4	24/07/1993	26/07/1993	205.06
5	26/08/1994	29/08/1994	205.86
6	08/09/1995	13/09/1995	106.98

NRSA has carried out special study for river Yamuna in order to ascertain its planeform upstream to Delhi. From the satellite based river morphology map, it is observed that, for most of the river reach from Karnal to Tajewala, the bank to bank river width is about 2 to 2.5 km. The river width is of the order of 1 to 1.5 km near Sitargarh (for about 2 km length) and upstream of Dilwara village (for about 1 km length). The river again shrinks to less than 1 km for about 6 km length upstream of Mawi bridge. Whereas, width of the active river flow channel varies from 200 to 300 metres except between Fatehpura to Barsat, where the width is of the order of 500 to 600 metre. Another interesting observation from the satellite based morphology map is that, the active river flow channel is swinging in direction from one bank to other bank of the river in its dry weather flow condition. These observations throw hydraulic characteristics of the river reach for possible channelisation to increase carrying flow capacity of the river by deepening and concretizing of the river reach.

4.3 Channelisation of Yamuna River near Delhi.

The above-mentioned satellite based map information can be ideally useful for flood control planning of Yamuna river. Channelisation of Yamuna river near Delhi to improve the flood carrying capacity is one such scheme being very seriously considered by the NCR of Delhi for quite sometime. With improved ground data of flood hydrology and flood hydraulics of the river now available and with application of very high resolution satellite data and physical model studies, such a river channelisation scheme can be planned and implemented.

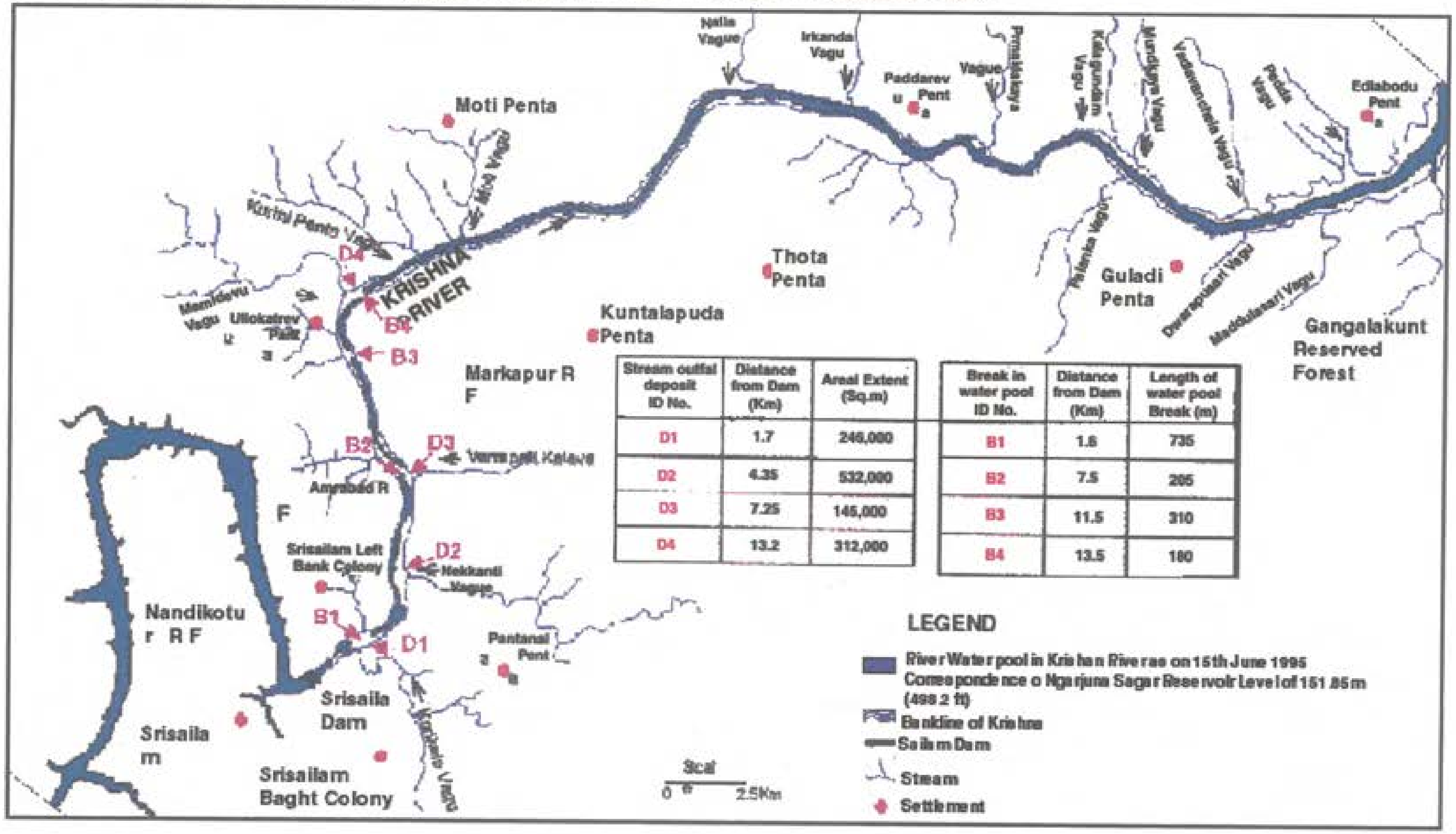
Figure.1 Stream Outfall Deposits in Krishan River downstream of Srisailam Dam Seen on PAN + LISS-III merged satellite image of 5March-2000



Karikela Vagu Deposit-D1

Nekkanti Vagu Deposit-D2

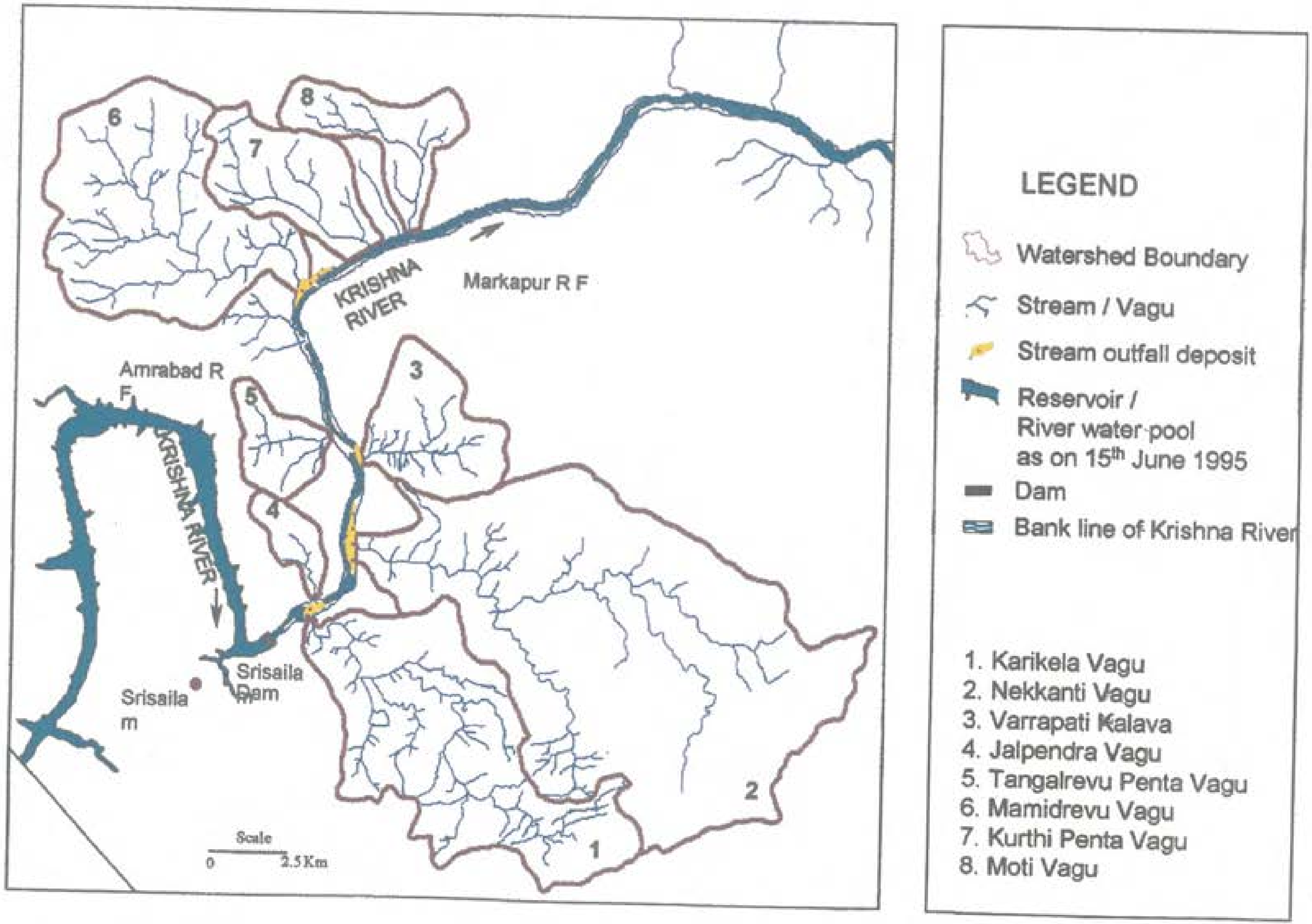
Figure-2 Location of Water Pool Breaks in Krishna River downstream of Srisailam Dam as on 15th June based on Digital Analysis of IRS-1B LISS-II Satellite Data



Stream outfall deposit ID No.	Distance from Dam (Km)	Areal Extent (Sq.m)
D1	1.7	246,000
D2	4.35	532,000
D3	7.25	145,000
D4	13.2	312,000

Break in water pool ID No.	Distance from Dam (Km)	Length of water pool Break (m)
B1	1.6	735
B2	7.5	205
B3	11.5	310
B4	13.5	180

Figure.3 Watersheds of Streams (Vagu) Joining Krishna River downstream of Srisailam Dam & Contributing Stream Outfall Deposits



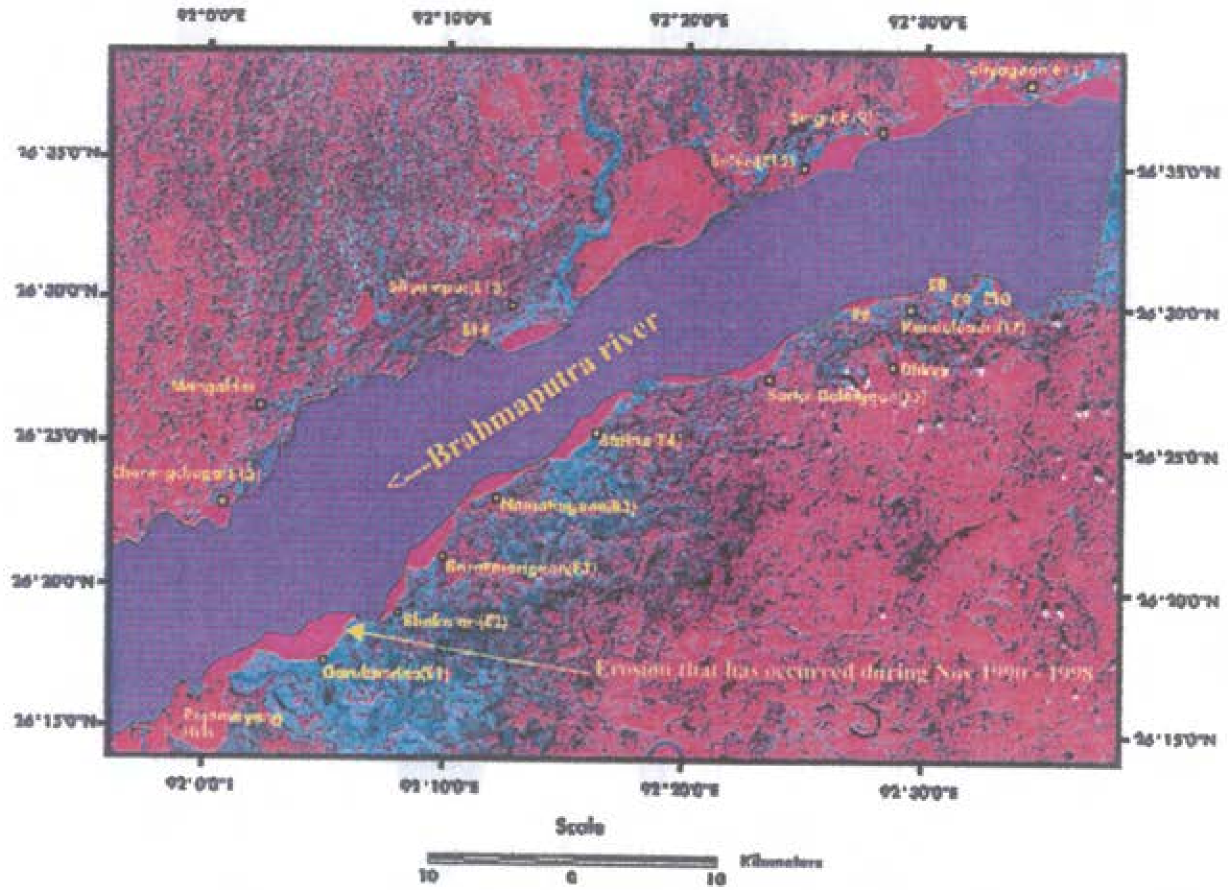


Figure.6 : Satellite Image of Brahmaputra River Reach subject to Bank Erosion & Deposition

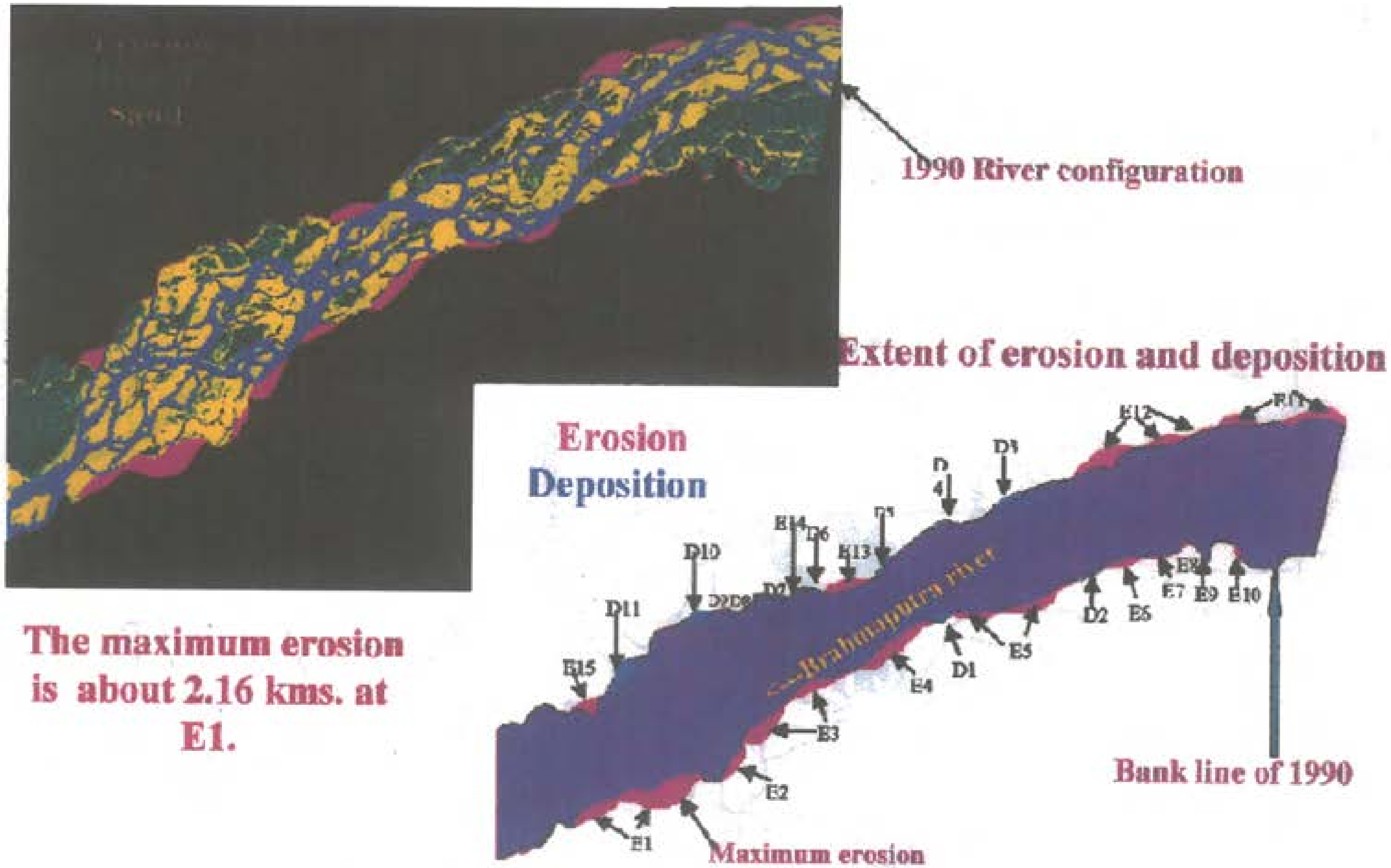
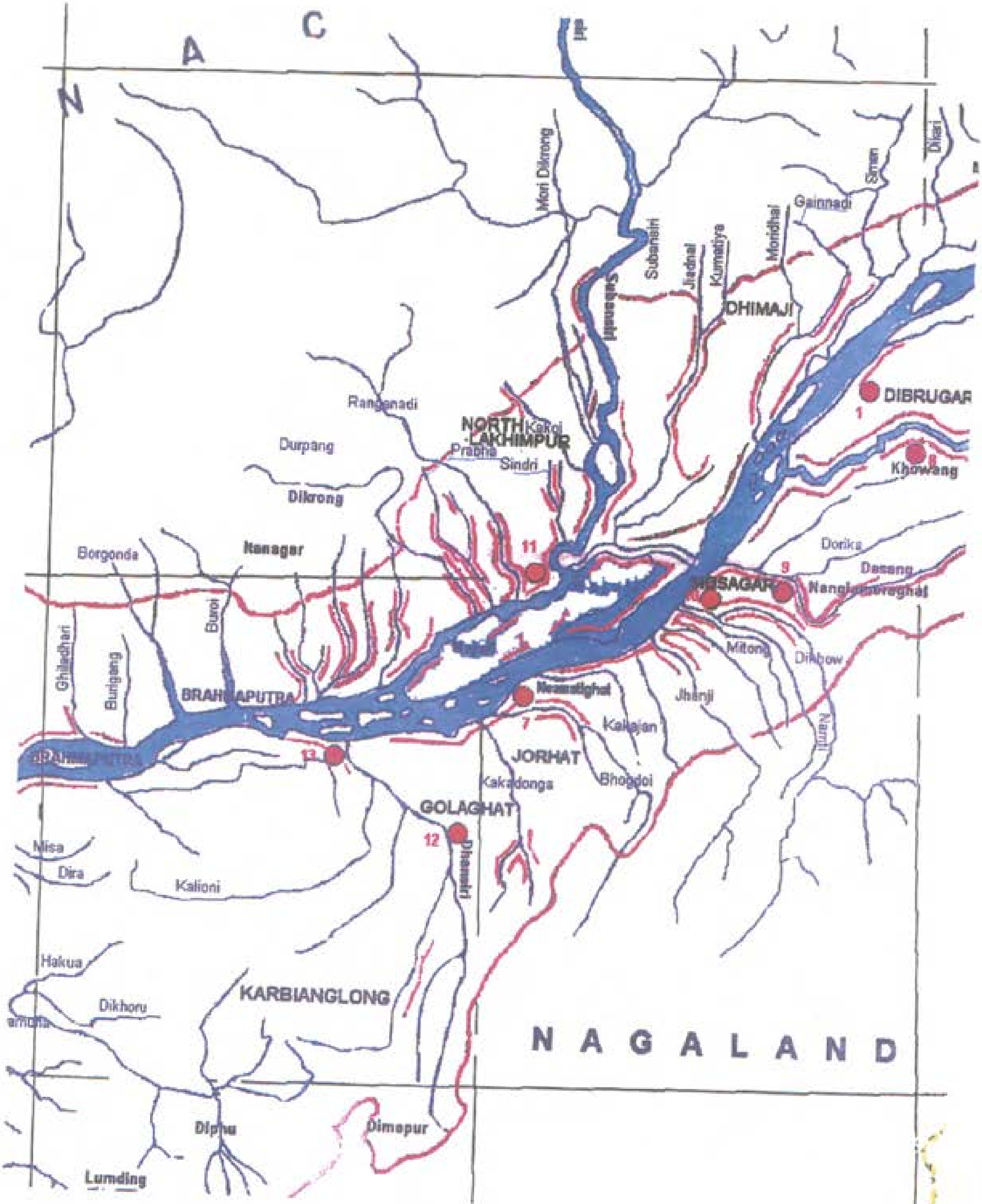


Figure .7 : River Configuration Map & Quantitative Estimate of Bank Erosion & Deposition in Brahmaputra River Reach from Tallyagaon to Rajamayang Hills, derived from Satellite Digital Data of the year 1990


Mori Dikrong
Subansiri
Jiadhal
Kumatiya
Moridhal
Gainnadi
DHIMAJI
Ranganadi
NORTH LAKHIMPUR
Kakoi
Durpang
Sindri
Dikrong
DIBRUGAR
1
Khowang
8
Borgonda
Itanagar
11
Dorika
Dasang
9
Mitong
Dikhow
Ghiladhari
Buroi
Burigang
BRAHMAPUTRA
Neamatighat
Jhanji
7
Kakajan
JORHAT
Kakadonga
Bhogdoi
13
GOLAGHAT
12
Dhansiri
Misa
Dira
Kalioni
Hakua
Dikhoru
KARBIANGLONG
NAGALAND
Diphu
Dimapur
Lumding

CHAPTER -VIII

RESEARCH AND DEVELOPMENT IN THE FIELD AND FUTURE DIRECTIONS

1.0 INTRODUCTION

For flood management activities, a river basin is the most suitable and appropriate unit for planning and implementation of various programmes. For optimal development and management of water resources, an integrated approach at the river basin or sub-basin level shall be the only criteria. Hence, there is a need of motivation progressively beyond the limited vision of specifying the interests of a basin state in the waters of the basin to meet the legitimate needs of water deficit basins by harnessing water surplus. This calls for appropriate research and development in the area of water resources.

The management of silt in a river can be achieved through various means. Some of these are :-

i. Catchment area treatment
ii. Rainwater harvesting
iii. Creation of embankments
iv. Constructing the drainage channels on the downstream
v. Creation of reservoirs in the downstream
vi. Dredging

Some of these have already been discussed in details in the report. However, it may be noted that general solution for all rivers is not possible especially for all reaches. Dredging may be of great help for navigation in small stretches but it may not be a solution in general rivers as the dredging will not effect the water level but will only decrease the velocity.

Keeping in view the importance of minimizing sediment deposition in rivers, it is proposed to discuss below various methods in details:

2.0 METHODS OF MINIMIZING SEDIMENT DEPOSITING IN A RIVER/ RESERVOIR

2.1 Reduction of Sediment Inflow by Soil Conservation

Soil conservation methods for preventing the movement of soil particles or preventing the transport of sediment include watershed structures and land-treatment measures in the watershed.

Several types of structures may be built in a watershed, e.g. sedimentation basins to store sediment permanently for the design life of the reservoir or to store sediment for specific storm runoffs before periodic cleanout; drop inlets and chutes for reduction of gully erosion; stream-bank revertments to reduce stream-bank erosion ; and sills or drop structures for stream-bed stabilisation.

Watershed land-treatment measures to reduce sheet erosion include soil improvement, proper tillage methods, strip cropping, terracing and crop rotations.

If the watershed is not very large, the effect of soil conservation can be felt in a short time. According to the experience in the United States, soil loss can be reduced by as much as 95% by employing no tillage rather than the conventional tillage. But, if vast areas with poor natural conditions are involved, the soil conservation works can hardly be effective in a short period of time. The effectiveness of the soil conservation for large catchment areas can not be estimated with accuracy.

2.2 Trapping and Retention of Sediment by a Vegetative Screen

A vegetative screen is most effective in preventing the sediment from entering the reservoir or lake. Such screens whether artificial or natural at the head of the reservoir serve to diffuse the incoming flow, reduce its velocity and cause the sediment to deposit. Thus, a great amount of incoming sediment can be trapped at the head of the reservoir and prevented from penetrating farther into the basin.

It should be pointed out that the sediment deposited in an area of vegetation of the flood plain of a delta raises the same problems as progressive deposition on the delta after the dam completion. Farm lands in such sites may be injured through the rising watertable, and levees for flood protection might need to be constructed or heightened as a result of further deposition of sediment, if there are towns or industrial sites existing upstream of the reservoir.

2.3 Bypassing of Heavily Sediment – Laden Flows

The construction of bypassing channels or conduits is one of the principal methods used to control the inflow of sediment to impounding reservoirs. Generally, a great amount of sediment is carried by the river flow during the flood periods, especially in the arid and semi-arid regions. Thus, when a large part of the flow with high concentration is bypassed through a channel or tunnel, serious silting in the reservoir may be avoided.

3.0 METHOD OF MAXIMISING SEDIMENT THROUGH FLOW

3.1 Flow Regulation During Floods

The purpose of regulating the flow by a reservoir during the flood season is to release as much sediment as possible from the reservoir by making use of the silt carrying capacity of the flood. Generally, the regulation of flow is achieved by lowering the water level during the flood season by operating the deep or bottom outlets under controlled (partial opening) or uncontrolled conditions.

During the period of rising water level of a flood in a detention reservoir, the outflow silt discharge is always smaller than that of the inflow, as a result of the backwater effect, and the consequent decrease in the velocity of the flood waters. Subsequently, during the lowering of the water level at the dam in the absence of a backwater effect, the outflow silt discharge is often greater than the inflow, due to erosion occurring in the reservoir.

3.2 Drawdown Flushing :

Drawing down the water level in a reservoir for the sake of reducing the amount of sedimentation, or in order to induce erosion of the deposited sediment to recover storage capacity, is a method often used in reservoirs, especially those of hydroelectric power stations. The efficiency of sediment flushing depends on the topographic position of the reservoir, the capacity of the outlet, the outlet elevation, the characteristics of the inflowing sediment, the mode of operation, the time duration of flushing, the flushing discharge etc.

3.3 Density Current Flushing

The venting of density currents has long been considered an effective means of relieving the rate of reservoir silting, especially in impounding reservoirs.

Qualitative laboratory flume tests on the possibility of venting density currents were performed in the twenties, making use of turbid water to form the density current and of saline water instead of cold water. These experiments were in accordance with occurrences observed at lakes and reservoirs.

Field observations have been made in many reservoirs following the recognition of the phenomenon of density currents. Some travelled more than 100 km. Before being vented out through the diversion outlet in Lake Mead, USA, revealing the potentiality for venting density currents in restricting siltation in reservoirs, e.g., the Sautet Reservoir in France, the Metka and the Groshnitza reservoirs in Yugoslavia, and the Naulek reservoir in the USSR.

3.4 Bottom Outlet Structures

Whenever reservoir silting is likely to be a problem, the potentialities of bottom outlet release of sediment through a dam should be considered in the dam design; and, at the same time, the form of reservoir operation should also be taken into consideration. Of all the methods for sediment sluicing, the use of bottom outlets seems to be one of the most effective.

1. Bottom outlets may be operated for under sluicing the flood, or draining the reservoir under emergency conditions when lowering the reservoir water level is urgently needed in a short period of time.

2. Bottom outlets may be used for sluicing sediment by drawing down the water level in the reservoir, to release sediment deposits (silts, sands and gravels), which are eroded by the tractive force of the flow. Similarly, density currents may be vented from an impounding reservoir.

3. When bottom outlets are located below the power intake, they may be useful in preventing the silt flow entering the power intake, minimizing the possibility of wear occurring in water turbines.

4.0 RECOVERY OF STORAGE

4.1 Flushing of Deposited Sediment :

Reservoir emptying operations may be used periodically for small reservoirs where the storage could not be maintained for beneficial use after a period of several years of operation. Since a great part of the useful storage capacity in a small reservoir is located near the dam site, the sediment deposits may be removed by flood flow if the outlet gates are left open for a period of time. The channel, thus scoured out in the deposits, becomes a part of the storage capacity.

Emptying and flushing operations may be used in reservoirs where a balance between deposition and erosion can not be obtained by flushing sediment during the flood and storing clearer water during the non flood seasons.

4.2 Dredging :

Dredging to remove sediment from the river / reservoir is undertaken were :

a. flushing is not successful,
b. the building of a bypass is impossible,

c. the drawdown of the pool level for flushing is not allowed for the sake of saving water,

d. the dam is irreplaceable with no possibility of further raising the dam height, or

e. the energy consumed in flushing by lowering pool level or emptying the reservoir is uneconomic for reducing the rate of silting in the reservoir.

Generally speaking, dredging is an expensive means of restoring the storage capacity of unless the deposits removed can be used for the beneficial purposes. Some coarse sediments dredged may be used as construction material.

Dredging in reservoirs is successful and can be performed under different conditions as follows :-

1. To recover the storage capacity of small-sized reservoirs, small compensation basins, gravel, retention basins; or to partially recover the capacity of medium sized reservoirs.
2. To clear the deposits in the backwater ponds of a chain of power stations, to lower the flood level in the river channel, or to maintain a necessary navigation depth in the backwater sedimentation reach of the reservoir.

5.0 R&D IN THE FIELD AND FUTURE DIRECTIONS

Physical and mathematical modelling is required to be taken up for vulnerable reaches. Mathematical modelling for siltation is extremely complex and shall require use of high computing capabilities, understanding of physical processes and complex models. Specially for rivers which are flowing from Nepal and are carrying heavy silt loads, afforestation needs to be taken up in the upper catchments. In case landslide are the problems, this would need appropriately treating such areas.

It would be necessary to take 3 - 4 model sites having siltation and looking at the siltation problems, their cause and seeking solutions. In case of rivers which have not stabilized with permanent river training works, dredging need to be carried out for maintenance of channels for navigation. Hence selective dredging may be carried out locally for navigational purposes. Before taking up large dredging operation in a large river, the necessity of taking up the dredging, its actual effect on long term siltation needs to be studied through a physical model. The experience of other countries specially China who are facing similar measure problems need to be collected and utilised. Presently in India the dredging is carried out locally in a width of 30 - 50 meters and in stretch of 1 km. Normally the dredged material is dumped in the river itself. This phenomena needs to be carefully studied as it may not work in case of very large rivers like

Ganga, Brahmaputra or Kosi. The economics of the dredging operation also needs to be worked out. Also, the environmental impact of dumping large quantities of dredged material in the river itself or on the banks needs to be studied. Hence, selective dredging may be taken up for vulnerable reaches.

In summing up, the R&D efforts need to be carried out mainly on the following :

i. Increased research into the erosion and sedimentation processes specially through the development of a unified system of erosion and sedimentation in selected reaches. Increased emphasis on the practical evaluation of water erosion control methodologies with emphasis on the communication of practical information to policy makers.

ii. Even though some efforts have been made to develop stable-channel design procedure taking into account the sediment load as one of the factors, the method still needs modification. Method of design of channels flowing through cohesive material and transporting large quantities of fine material needs to be developed also.

iii. At present the devices like sediment excluders and extractors are designed using thumb rules and model studies which give only qualitative information. As a result, even though some excluders and extractors are working satisfactorily, the performance of others is unsatisfactory. Hence there is need for rationalising their design procedures taking into account the theory of sediment transport. Some attempts have been made in this regard in India and abroad; however, much more needs to be done in this respect.

iv. If excessive scour takes place the safety of structure is endangered and in the extreme case the structure may fall. Therefore, one must be able to anticipate the extent of maximum scour that can take place and provide measures to control it. Several relationships for scour have been developed from laboratory studies and few field data but there is need to collect reliable field data to verify these relations. Very little work is done in developing protective measures. The age old methods of rip-rap and launching apron provision are still the best methods available.

v. Generally, it is assumed that the planform is not changed. However, if banks are easily erodible, planform viz., straight, meandering or braided - can change. The analysis then becomes somewhat more complicated. While methods are available for quantitative prediction of changes in slope due to changed conditions, at present it is not possible to predict the planform changes very accurately even qualitatively.

vi. A knowledge of the sediment load, carried by a stream is necessary for the solution of practically all problems associated with rivers. Ever since, the pioneering work of Du Boys in 1879, many empirical and semi-empirical methods have been put forward for the calculation of bed load transport rates. But the accuracy of calculation of bed load transport rates by using the available methods is far from satisfactory.

vii. In recent years, denudation of catchment through human activity by way of agriculture, deforestation, extensive grazing etc. has been progressively accelerating soil erosion and disturbing solid liquid equilibrium in the rivers. Unusual sedimentation on the river beds as also in the storage reservoirs and irrigation channels have been resulted in drainage congestion, and reduction in the efficiency of canals and storage capacity of reservoirs. Excessive sedimentation in rivers is also responsible for higher flood levels besides posing problems in navigation channels. Regular sediment survey in rivers has, therefore, assumed great importance. Periodic sediment transport data of a stream provides vital information on the rate of soil erosion and changing land use pattern in the catchment and therefore forms the basis of planning, designing and maintaining water resources projects in a river basin as well as for preservation of the catchment ecosystem.

viii. It is necessary to use depth integrating samplers and time integrating samplers in place of bottle type sampler which will measure the actual concentration of the sediment in a given vertical. Automatic type sampling instruments are of recent origin. It is necessary to use such instruments at some of the stations of vital importance.

ix. In hilly areas where it is problematic to measure the suspended sediment concentration accurately, it would be appropriate to adopt tracer techniques in the near future.

x. Analysis of bed material samples using electronic sedimentation balance shall be resorted to get a reliable and accurate particle size distribution curves of bed material samples.

xi. Presently methods are available either analytical or numerical to compute transport bed profiles in alluvial stream under simplifying conditions. These can be used to make engineering predictions needed in the management of alluvial rivers as a consequence of man-made interference in the river regime.

xii. The effective solution to desilting is erosion control in the upstream watersheds. It is important to remember that as far as water erosion is concerned, prevention is always easier and better than cure.

xiii. No single solution will be appropriate for every location. The approach to flood damage reduction that is likely to yield the most benefit at the lowest cost in many parts of any basin is one that retains water on the landscape rather than transferring it quickly downstream. The approach requires the restoration of some of the pre-settlement characteristics of watershed, such as permanent vegetative cover, an abundance of wetlands and soils with high organic contents that help reduce the flood peaks and contribute to streamflows during dry seasons.

xiv. Increased international cooperation for successful navigation of soil and water conservation programmes.

CHAPTER – IX

RECOMMENDATIONS AND SUGGESTIONS

1.0 INTRODUCTION :

River siltation has apparently been not studied in totality by any of the past investigations. Silting of river bed is not a new phenomenon as alluvium plains have been formed by silt carried by rivers. The river while flowing from upland to lowland carries along with it silt, a part of which is dropped by the river en route to its outfall.

The Geological Society of India (No. 41, 1998) has brought out a comprehensive report on Floods in India. Prof. Thomas Hofer, Deptt. Of Geology has studied floods in India for the last 40 years (1953 to 1993) and has provided a preliminary indicator of siltation of rivers and this shows that there is no increasing trend of magnitude or frequency.

India has been pursuing flood control schemes since 1954. The flood damage has been simultaneously rising notwithstanding considerable expenditure incurred on these schemes in the past few decades. This is more due to encroachment of flood plains. Embankments are effective for a low flood but for high floods they may rather be a hindrance as it cannot afford protection in case of high floods, though it fosters the impression of security. However, embankments serve an important function in flood management.

Flooding in Ganga, Brahmaputra, Meghna System is not new. Shifting of the course of these rivers in certain reaches is also a common phenomenon. For example, the Brahmaputra, which before 1789 was a tributary of Meghna, joined Ganga following severe earthquake which occurred in 1789.

The Yellow river of China in its lower reaches has been severely subjected to silting so much so that its river bed is about 3-3.5 m above the general ground level. In case of Yellow river, Chinese experts have taken resort to raising of embankment height in order to offset against the consequent rise in river stage.

In pursuance of harnessing water resources potential several schemes have been implemented in rivers following which morphological changes have taken place. Flood control schemes especially embankments are said to affect morphological behaviour of a river as they confine the river flow from spreading on either side. Embankments have been constructed on flood prone rivers in almost all countries where flooding is experienced. In India several thousand kms. of embankment are existing along flood prone rivers especially in Ganga and Brahmaputra river systems. Therefore, theoretically speaking these rivers are supposed to undergo morphological changes.

The Committee ,therefore, endeavoured to find out the published literature related to such studies which could corroborate the above line of thinking. The Committee did not pursue any special study in order to determine the true status of silting in Indian rivers. This limitation notwithstanding, the Committee collected voluminous literature on silting of rivers. Several State Governments viz. Orissa, West Bengal and Assam submitted materials on silting and its effects in response to the request of the Committee. The studies carried out by WATER AND POWER CONSULTANCY SERVICES (INDIA) LIMITED (A Government of India Undertaking) for North Eastern Council on "Morphological studies of River Brahmaputra" in 1993 thoroughly looked into the morphological behaviour of river Brahmaputra including aggradation.

It is a known fact that tidal rivers are generally prone to silting thereby causing drainage congestion and flooding. Likewise, the confluence of a tributary to the main channel is generally subjected to silting. Right from the first meeting dredging has been an important topic of discussion. Its efficacy for flood management has been in doubt in view of the several practical problems such as cost involved, disposal of dredged material and sustainability of the solution suggested. To quote two typical examples, West Bengal Government could not carry out dredging operation in Ichamati river due to non-availability of suitable land for disposal of the dredged material. Assam Govt. in 1978 carried out dredging operation in Brahmaputra which was abandoned subsequently as it had no positive impact. Dredging has, therefore, been found to be not so effective in general. However, the Committee has suggested *selective dredging* depending on local conditions to improve the hydraulic characteristics of the river.

2.0 COMMITTEE MEETINGS

The Committee held 7 meetings, all in New Delhi where experts from Central Water Commission, Brahmaputra Board, GFCC, GSI, NRSA, NIH, JNU, IWAI, CWPRS, DCI, Government of Assam, Bihar, West Bengal and Orissa met to deliberate upon the subject. Two background notes for the first and second meetings were circulated by Central Water Commission wherein some of the available information was compiled so as to facilitate members to hold discussions.

3.0 PROBLEM OF SILTING:

Aggradation is a process in which the bed of a river rises as a consequence of deposition of sediment. Continuous aggradation in a river may lead to reduction of carrying capacity and hence overtopping.

Due to aggradation in Irlamaz river in Turkey, the city Salihi was flooded and rail road damaged. Government of Turkey took precautions to stop aggradation. Further details, however, could be not available in this regard. The Yellow river of China whose bed level is about 3-3.5 meters above the general ground level, is a case of great interest.

In respect of our own country, several tidal rivers in Orissa have been reported to be subjected to silting causing drainage congestion and flooding. The river Brahmaputra at Dibrugarh had undergone morphological changes following an earthquake of 1950. The bed level had risen in considerable reaches resulting in the raise of minimum water level substantially. The morphological report of Brahmaputra Board has mentioned aggradation in the upper reach of Brahmaputra.

In case the silting is taking place in a river bed continuously, either the bed level is to be lowered or embankment raised to make good the loss of carrying capacity. There can hardly be any solution which can be universally adopted. The solution in fact has to be location specific.

4.0 STATUS OF SILTING

The Committee thoroughly looked into this aspect with the help of available literature collected by CWC. In order to work out quantitative figure of aggradation/degradation, a few sites on Ganga, Brahmaputra, Godavari, Krishna,etc, were selected where cross-sectional areas of last 5-10 years were superimposed. The result has been appended in order to buttress the view that aggradation, contrary to the general impression, is not pronounced and alarming. This can be so in respect of many other Indian rivers also.

The Brahmaputra Board carried out detailed analysis of sixty five cross sections taken along the river Brahmaputra which has been reflected in the Master Plan prepared by Brahmaputra Board. It was also concluded in the report of NEC prepared by WAPCOS on Morphological studies of river Brahmaputra, 1993 that aggradation is limited to very short length, that too for a short period (Para 8.2.5 of Morphological studies of River Brahmaputra, 1993) Over a long period of 32 years from 1957 to 1989, the study indicates that an overall degradation in almost the whole length of the river has taken place.

As per the literature available from Water Resources Deparments, Orissa and West Bengal, coastal rivers of Orissa and West Bengal have been subjected to aggradation causing drainage congestion and flooding. Kosi and other rivers of Bihar have also been reported to induce silting in river beds. This, however, has not been substantiated by specific data. Carrying capacity of a river should, therefore, be monitored on regular basis to obtain a correct knowledge regarding aggradation/degradation. Obviously, relevant data are required to be collected in future; this could then be analysed to understand the nature of silting process.

5.0 IDENTIFICATION OF CAUSE AND EXTENT OF SILTATION IN RIVERS.

Silt flow is an inherent part of river flow. The flow from steep gradient to low gradient is always accompanied by erosion in upper reach and deposition in the lower reach. Himalayan rivers originate from geologically unstable regions of Himalayas which are seismically active as well. Faulty land use practices/deforestation have exacerbated the erosion problem in hilly regions of Himalayas. Peninsular rivers are not so much prone to siltation. Coastal rivers have intrinsic nature of siltation mainly due to natural and tidal causes. Though there is heavy sediment load in rivers, the natural process of *'self scouring'* ensures that there is no substantial aggradation, in totality.

6.0 MEASURES FOR MINIMIZING SILTATION.

As siltation is a part of river system, earlier Committees/experts have stressed upon the necessity of reducing silt load in rivers particularly those which are flood prone. Morphological behaviour of a river is greatly influenced by silt load that a river carries.

The method of minimizing siltation may be of two fold –one that is required in the catchment and the other in the river itself. The method to be adopted in the former viz the catchment may include afforestation, right practice of land use, catchment area treatment, and others. The method in respect of later viz 'the river itself' may include construction of suitable hydraulic structures that may trap silt. Embankment along the aggrading river should be constructed, only after proper studies are made on its behaviour especially due to sedimentation load & resultant morphological changes.

7.0 EFFICACY OF DESILTING OF RIVER BED VIS-À-VIS FLOOD PROBLEM

The Committee considered this aspect and found desilting in general is not feasible technically, due to several reasons like non-sustainability, non-availability of vast land required for the disposal of dredged material, etc. The desilting by dredging operation .was specifically discussed by committee. It arrived at the conclusion that dredging in general should not be resorted particularly in major rivers. There are, of course, some locations such as tidal rivers, confluence points and the likes which can be tackled by desilting after thorough examination.

Desilting of rivers can marginally minimize the magnitude of floods and be effective only for a short period. This cannot be viewed in isolation of other approaches to manage floods. In view of the limited scope, desilting is not recommended on a large scale. However, desilting can be done in vulnerable reaches for some specific purpose which are to be identified by the state governments and local people, and the experience should be evaluated for further applicability. For navigation purpose the river reaches in the waterway path need to be dredged every year, to have minimum depth of water. However, this will have insignificant effect on flood control.

8.0 APPROPRIATE TECHNOLOGY / METHOD OF DESILTING OF RIVERS , IF FOUND TECHNICALLY FEASIBLE.

The Committee is of the opinion that in cases where siltation has taken on one bank and erosion on the other bank of the river, silt can be removed from the deposited area and dumped on the suitable area with proper investigation.This can be by simple dozing. Experiments may be conducted to assess the effectiveness of artificial flood waves in flushing the silt downstream especially around the confluence of large tributaries with main river.

All major rivers of North India straddle the international border between India and Nepal /Bhutan /Myanmar. The catchment area treatment will necessitate an understanding with these countries so as to undertake such schemes and implement. For example, understanding with Royal Govt. of Nepal is required to implement schemes which may reduce silt load in rivers of North Bihar in general and Kosi, in particular.

The Department of Sedimentation, Chinese Institute of Water Resources and Hydropower Research is understood to have taken up feasibility study of desilting of 20 medium and minor rivers in Bangladesh(funded by UNDP). It will be worthwhile if Ministry of Water Resources, Government of India can establish rapport with the Department of Sedimentation, China for exchange of information in this project.

The feasibility of conducting similar studies upstream of Farakka in order to manage the silt problem may be explored.

9.0 DETERMINATION OF ECONOMIC VIABILITY OF DESILTING IN RIVERS

The Committee is of the opinion that desilting of rivers for flood control is not an economically viable solution.

10. TO PROPOSE A REALISTIC OPERATIONAL PROGRAMME IN A TIME BOUND MANNER.

The Committee is of the view that a specific scientific study needs to be taken up by NEHARI under Brahmaputra Board, Irrigation Research Institute, Roorkee, River Research Institute, Calcutta, CWPRS, Pune and other similar organisation in the country to establish the cause of aggradation/degradation in any affected river and to suggest different remedial measures to minimize/remove the siltation problem. Once these measures are implemented and proved successful, the same can be considered for other affected areas with similar conditions.

CHAPTER - X

LITERATURE AND REFERENCES

1.	Problems of siltation in rivers of Orissa	-	Shri B.C.Nayak Former E-in-C, Orissa
2.	Bank erosion study for part of river Brahmaputra (1990-98)	-	Task Force SR&A
3.	Brief note on siltation problem in river of Assam		Flood Control Deptt Govt. of Assam
4..	Report on shore protection work and dredging works in Devi rivers	-	Govt. of Orissa
5.	Evaluation report on desilting works in Cauvery Delta System	-	PWAD,WRO Tamil Nadu
6.	River sedimentation	-	Morphology Dte. CWC, New Delhi
8.	Mississippi river	-	Prof. Sivasami JNU, New Delhi
9.	Report of reservoir sedimentation committee.	-	MOWR, July 1985
10.	Sedimentation studies in reservoirs	-	CBIP, New Delhi
11.	Special problem and survey and investigation using remote sensing Techniques for siltation of river of India	-	NRSA, Hyderabad
12.	Water Resources development in China,	-	CBI&P Publication 1992.
13.	Seismotectonic Scenario of Himalaya and its Recent Developments	-	Acharya, S.K. and Narula, P.L. (1998) Proc. Eleventh Symp. On Eqk. Engg. Dec. 17-19, Roorkee, 3-18.

14. The structure of Siang Window, its evolution and bearing on the nature of eastern syntaxis of the Himalaya, - Acharya,S.K. and Sengupta, S. (1998) Nat. Acad. Sci. Letters, 21, 5 & 6, 177-192.

15. Earthquakes of Peninsular India. A seismotectonic study, - Chandra, U. (1977) Bull. Seism. Soc.Am., 65, 5

16. Siltation studies in Bhakra catchment district Bilaspur, Himachal Pradesh , - Chopra S. (1980-81) Unpub. GSI Report (F S – 1980-81)

17 Erosion and sedimentation in Nepal Himalaya, - Galay, V. (1987) Water and Energy Commission/Secretariat H.M. Govt. of Nepal, Report

18. Brahmputra River, Assam, India: Physiography, basin denudation and channel aggradation, - Goswami, D.C. (1985) Water Resource Research, 21, 959-978

19. Fluvial Regime and Flood Hydrology of the Brahmputra River, Assam, - Goswami, D.C. (1998) Flood studies in India, Mem. 41, Geol.Soc.Ind., 53-76

20. Geology of the "Autochthonous Folded Belt", Jammu and Kashmir Himalaya with special reference to Panjal Thrust. - Jangpangi, B.S. (1986) Jour. Pal. Soc. India, 31, 39-51

26. Seismicity of Northeast India and surroundings-Developments over the past 100 years; Proc.Workshop on The Great Shillong Earthquake-1897: - Kayal, J.R. (1997) A Centennial Retro-spective, Shillong

27. Structure and Tectonics of Himalaya, Geology and Techtonics of Himalaya, - Kumar, G., Sinha Roy, S. and Ray, K.K. (1989). Geol. Surv. Ind. Spl. Publ., 26, 85-112.

28. Field measurements on erosion and sedimentation in Nepal. - Laban, P. (1987), Deptt. Soil, Consvn. And Water-shed Mgmt. Kathmandu, Nepal, Paper No. 5

29.	Seismotectonic Evaluation of North West Himalaya.	-	Narula, P.L. (1991). GSI Rec. 124 (8), 193-194.
30.	Neotectonic Activity in the Himalaya, Structure and Tectonics of Himalaya,	-	Narula, P.L., Shome, S.K. and Nandy, D.R. (1989) Geol. Surv. Ind. Spl. Publ. 26, 199-141
31.	Seismotectonics of Himalayan Collision Zone:Geometry of Under thrusting Indian Plate Beneath the Himalayas,	-	Ni, J. and Barazangi, M. (1984), Jour, Geophy. Reas., 89, 1147-1163.
32.	Intra Plate Seismicity of Peninsular India.- Proc. ISEG Symp. HREGE'99,		Pande, P. (1999), Bhopal Jour. Engg.Geo. XXVII, 4, 152-160
33.	Plate Tectonics and Himalayan	-	Powell, C.M.A. and Conaghan, P.J. (1973) Earth and Planetary Sci. Lett., 20, 1-12
34.	Lineament fabric of Madhya Pradesh and Maharashtra and its tectonic significance.	-	Rajurkar, S.T., Bhate, V.D. and Sharma, S.B. (1990) In: Precambrian of Central India. Geol. Surv. Ind. Spl. Pub. 28, 241-259.
35.	Channel and Flow Geometry,	-	Richards, K.S. (1977). Progr. In .Physi,Geogrph., 1, 65-102
36.	Great detachment earthquakes along the Himalayan Arc and long term forecasting:	-	Seeber, L. and Armbruster J.G. (1981), Earthquake Prediction and International Review, Am. Geophy. Union, Morris, Ewing Sr., 4, 259-177
37.	Flood Hydrology and Flood Management in India,	-	Seth, S.M. (1998), Flood Studies in India, Mem.41, Geol. Soc. India, 155-172.

38.	An approach to meet the challenge - of unpredictable hydrology in small catchments with special reference to Kandi Watershed Area, Punjab,		Sharda, Y.P. and Bagchi J. (2001), Proc. Nat, Symp Role of Earth Sci. in Intg. Devpt. And Related Soc. Issues, GSI Spl. Publ. 65, 11, 169-174
39.	Flood Hazards of North Bihar Rivers, Indo Gangetic Plans,	-	Sinha, Rajiv and Jain, Vikrant (1998), Flood Studies in India, Mem.41, Geol. Soc. India 27-52
40.	Sediment Transport : New Approach and Analysis J. Hyd. Div., ASCE, 99 (11) 2041-2060	-	Ackers, P., and White, W.R. (1973)
41.	'Sedimentation Engineering', by the Task Committee on Preparation of Manual in Sedimentation	-	ASCE (1975), Ed. Vito A. Venoni
42.	Practical Computation of Bed Material Discharge' J. Hyd. Div., ASCE, 90(2)	-	Colby B.R. (1964 a), Proc Paper 3843
43.	Discharge of Sands and Mean Velocity Relationships in Sand-Bed Streams', W.S.G.S.	-	Colby B.R. (1964 b), Prof. Paper 462
44.	A Monograph on Sediment Transport in Alluvial Streams Teknish Foriog	-	Engelund, F., and Hansen, E., (1967), Epenhagen Denmark
45.	Design of Stable Channels, Trans, ASCE, Vol. 120	-	Lane, E.W. (1958), Paper No. 2776, pp 234-1279
46.	Sediment Transport Under Ice, Cover J.Hyd. Engg., ASCE	-	Lau. Y.L. and Krishnappan B.G. (1985), 1(6) 934-950
47.	Modern Conception of the Mechanics of Fluid Turbulence', Trans, ASCE, Vol. 102	-	Rouse H. (1937 a), Paper No. 1965, pp 463-543
48.	Nomogram for Settling Velocity of Spheres', Division of Geology and Geography, Exhibit D Report of the Commission on Sedimentation	-	Rouse H.(1937 b), National Research Council, Washington,D.C. pp 57-64

49.	Re-modified Einstein Procedure for Sediment Load. J. Hyd. Div., ASCE	-	Shen H.W., and Hung C.S. 1983, 95(1), pp 225-248
50.	Anwendung der Aenlichkeitsmechanik under Turbulenziorschung auf die Geschiebebewegung', Mittelungen der Preussischen Veruchsanstalt fur Wasserbau und Schiffbau, Berlin, Germany	-	Shields A., (1936) Translated to English by W.P. Ott and J.C. Vab Un-Uchelen,California Institute of Technology, Pasadena, Calif., 1936
51.	Sediment Transport Theories : A review Proc. Inst. Civil Engg. (London)	-	White W.R.,Milli H. Crabbe A.D. (1975) Part 2, Vol.59, Pp 265-292
52.	Lecture notes on Sediment Transport for International Course in Hydraulic Engineering	-	Breusers H.M.C., Delft, Netherlands
53.	Lecture notes for training course in Hydraulic River Engineering And Application of Hydraulic Modelling Technique	-	Kulkami V.K.
54.	Reservoir Sedimentation – Handbook	-	Gregory L.Morris and Jiahna Fan
55.	Fluvial processes	-	Selim yahin M. et al
56.	Reservoir Sedimentation - Literature Survey	-	Shroff C.J.
57.	Evacuation of Sediment from Reservoir	-	Rodney White
58.	Floods: hydrological, sedimentological and geomorphological implications Wily Lewin J. 1989 Floods in Fluvial geomorphology	-	Beven, K.J. and Carling P.A. eds. 1989,
59.	River Channelisation, traditional Engg. Methods, physical consequences and Alternative Practices, Progress in Physical Geography 9, 44-73	-	Bookes, A. 1985

60.	Fluvial Forms & Processes – A new Perspective, Arnold	-	Knighton, A.D., 1998 Deptt. Of Geography, University of Shefield U.K.
61.	Channels environmental Crisis – an Enquiry into limits of National development	-	Smil, Vaclan 1993, M.E. M.E. Sharpe, New York
62.	Report of Rashtriya Barh Ayog, 1981	-	Govt. of India
63.	Report of the Regional Task Force for Flood Management, 1997	-	MOWR, Govt. of India
64.	Erosion, Sedimentation and flooding in river Kosi, 1993-94	-	National Institute of Hydrology
65.	Sediment Transport Technology	-	D.B.Simons & Fuat Senturk, W.R. Publication Colorado, USA 1977
66.	Morphological Studies of river Brahmaputra	-	North Eastern Council, Govt. of India
67.	The Kosi river – Its Morphology & Mechanics in Retrospect & Prospect	-	Morphology Dte., CWC, April, 1982
68.	Evacuation of Sediments from Reservoirs	-	Rodney White, Thomas Telford, 2001
69.	Fluvial Regime Flood Hydrology of the Brahmaputra river	-	D.C. Goswami, Memoir Geological Society of India No. 41, 1998
70.	Floods and Flood Control	-	R.J. Garde, Memoir Geological Society of India No. 41, 1998
71.	Remote Sensing and GIS in Flood Management in India	-	D.P.Rao, V.Bhanumurthy, G.S.Rao and P.Manjusri Memoir Geological Society of India No. 41, 1998
72.	Future Prospects for Past Floods in India	-	Victor R. Baker, Memoir Geological Society of India No. 41, 1998

73. Floods in Indian rivers and their Meteorological aspects - O.N. Dhar, IITM, Pune Memoir Geological Society of India No. 41, 1998

74. Reservoir Sedimentation Handbook - Gregory L. Morris & Jiahua Fan McGraw-Hill

REPORT
OF
THE COMMITTEE ON
SILTING OF RIVERS IN INDIA

VOLUME - II

ANNEXURES

GOVERNMENT OF INDIA
MINISTRY OF WATER RESOURCES
NEW DELHI
DECEMBER 2002

Problem of silting in rivers of Orissa

INTRODUCTION

Orissa is a maritime state situated in the eastem region of the country .The state has geographical area of 15.58 million hector and a long coast line of 477km on the east along the Bay of Bengal .The adjoining states of Orissa are West Bengal ,Jharhkand, Chhatisgarh & Andhra Pradesh .The average annual rainfall in the state is 1482mm and average annual runoff is 1,10,330 Mcum.

About 90% of the annual rainfall occurs in a span of mere 100 days during monsoon period During the cyclonic storms the daily rainfall has exceeded 400mm several times in the past The dry spell even during the monsoon period sometimes exceeds 20-30 days The Orissa is ravaged by flood,droughts, cyclones & heat wave all even occuring in different districts in the same year. The area prone to flood in this state is about 3.34 M.Ha in 21 districts .

The major rivers Subarnarekha, Budhabalanga Salandi ,Baitarani ,Brahmani ,Mahanadi, Rushikulya etc flow in the state & outfall to the Bay of Bengal .There are 11 river basins in the state. The name of basins with its catchment area are furnished below .

Sr. No.	Name of the Basin	Drainage area in Sq. Km.	
		Total	Within Orissa
I.	Mahanadi	141134	65628
II.	Brahmani	39269	22516
III.	Baitarani	14218	13482
IV.	Rusikulya	8200	8200
V.	Nagavali	9275	4500
VI.	Vansadhara	11510	8960
VII.	Bahuda	1118	890
VIII.	Indravati	41700	7400
IX.	Kolab	20427	10321
X.	Subarnrekha	19227	2982
XI.	Budhabalanga	4828	4828
			155707

Flood in the above rivers occur in most of the years due to .

1. High rainfall in the catchments during short period .
2. High rainfall in catchments below the reservoirs for which there is no control of regulation .
3. High rainfall in catchments below the reservoirs when the outflow from the reservoirs is high .
4. Non-release of flood water to the sea due to siltation in month of rivers .

Due to high flood in rivers the flood water levels rises up and breaches the river embankments resulting loss of crops & human habitation .

Siltation in rivers is a natural phenomena and occurs due to .

I. Deforestation ,cultivation ,quarrying in the catchments area .
II. Obstruction to free flow at outfall due to littoral drift .
III. Formation of horse shoe bends in the course of rivers and scour of river banks.

To control silt large-scale afforestation prevention of deforestation, construction of check dams ,strict preventions of quarrying & cultivation in the catchment is necessary .It is not necessary to desilt the river bed for entire length. The sediments deposited in navigable channels ,waterways have to be flushed out or removed periodically .But the following points are suggested to be taken up.

I. At critical vulnerable points where scour of river bank on one side is severe due to siltation in bed on other side within regime width siltation is to be removed manually, mechanically or by dredging .The silts will be used to raise & strengthen & widen the embankments ,construction of approach of bridges & filling the low-lying areas .It will be economical if 3 to 4 dredgers are purchased by Govt. for the use departmentally by govt. instead of dredging by Pvt. Agency

Some of the most vulnerable locations are as follows .

River Basin	Name of river / tributary	Location
Mahanadi Basin	Devi	Bauriakana
		Daleighai
		Kulasahi
		Sribantpur
		Podaruan
	Mahanadi	Singitali
Brahmani Basin	Brahmani	Srirampur
		Bankeswar
Badhabalaga Basin	Gamei river	Chudamani to outfall point
Subarnrekha Basin	Subarnrekha	Dahamunda

MAHANADI BASIN

Mahanadi ,the 6th biggest river. of India ,originates near village Pharasiya of Raipur district of Chatisgarh state .It runs 357 Km in Raipur & Bilashpur districts of Chatisgarh and 444 Km in Orissa and falls in Bay of Bengal .Out of its total catchment area of 141134 Sq.Km. ,65628 Sq.km. is in Orissa & 75506 Sq.km. in chatisgarh .

Deonath river ,a major tributary of Mahanadi ,has a ctachment area of 30761 Sq.Km. (21.70% of total catchment of Mahanadi) and runs in Chatisgarh state .

Mahanadi receives the river IB ,Sapua etc. on left & Jira ,Ong ,Tel ,Salki , Burtang, Kuaria, Kamei ,Rana etc on the right .It enters in to Delta at Naraj & branches to Kuakhia & Kathojodi .These branches also branch to several rivers & flow in Delta area.

A multipurpose major dam has been constructed across Mahanadi at Hirakud which control flood, generate power & provides irrigation. The Barrage have been constructed at Munduli & Jobra across Mahanadi. A barrage has been constructed at Jagatpur across Birupa river a branch of Mahanadi .Another barrage is being constructed at Cuttack across Kathajodi (Naraj Barrage).

II. Siltation problem in Mahanadi Basin

Longitudinal slope of the river Mahanadi & its tributaries are steep in upper reaches ,become flatter in middle reaches and turn level in estuaries .The upper course are noted predominantly for deep erosion i.e bed retrogression . Some portion of flowing silt is being deposited in Hirakud reservoir .The scoured materials are carried downstream by the flow & middle courses have evidence of both deep erosion & aggradation .In the lower reaches below Naraj where the bedslope & velocity are small .Sedimentation occurs .Bed siltation also occurs due to tidal obstruction to free flow of water to Bay of Bengal .Silt observation in being done at Naraj barrage site in Kathojodi .

Removal of silt in river Devi at Bauriakana

The river Devi is a major tributary of Kathajodi branch of Mahanadi river in Orissa . It flows in delta area .

The right embankment and berm from Bauriakana to Kandasahi is being scoured severely every year .This is most vulnerable location during & after flood .It is located in tidal reach .The riverbed level on right side and left side are at RL(-) 14M & RL(+) 4M respectively .

If any breach will occur ,it will affect crops in vast cultivable lands .The homestead lands in this thickly populated area will be damaged .Since last 40 years Govt. of Orissa has constructed number of spurs and revetment works . But those are damaged .Govt. of Orissa has taken up construction of three number of spurs out of cyclone damage repair grant .Still the erosion continues.

Hence the Govt. of Orissa had engaged Ocean Engineering Center and Civil Engineering Department of IIT Madras as consultant to advise on protection work needed at Bauriakana .

IIT Madras has suggested to remove the sand deposit of 17.50 Lakh Cum from left side bed to provide adequate waterway for flow of floodwater in addition to other flood control works like construction of spurs & revetment on right side .

Hence it is necessary to remove silt & sand from left side .The silt & sand will be used to raise & strengthen the embankment to withstand a flood of 12 lakh cusec ,which had been constructed earlier for 9 lakh cusec of flood .

Removing Sand from River Bed at Daleighai in Kathajodi and Sri Bantpur ,Podaruan & Kulashi in River Devi

Heavy scouring of embankment is observed during flood at Daleighai in river Kathajodi and at Sri Bantpur ,Podaruan & Kulasahi in river Devi .Due to meandering of the river large scale ,accumulation of sand is observed either on the middle or on one side of the river resulting to constriction of waterway ,for which the deep channel of the river is noticed very close to the embankment During heavy flood when the maximum discharge of river is passing in a constricted waterway , scouring of the toe of embankment and bank occur due to high velocity of water .In some cases the embankment and also the village situated adjacent to the embankment have been shifted several times .The burning examples are the villages like Daleighai ,Sri bantpur ,Podaruan & Kulasahi .

Within last 50 years Govt. of Orissa has constructed 5 nos. of spur and 200 m revetment at Daleighai out of which 2 nos of spurs have been damaged 500m of revetment with launching at Sri bantpur & 200m of revetment with launching at Podaruan have been completely damaged during super cyclone 1999 .Repair is being taken up under cyclone repair grant .

In order to save the loss of lives and property there is necessity for immediate desiltation of sand at these locations as suggested by a team of experts from IIT Madras .As per the suggestion the bed of the river should be cleaned & desilted in addition to the protective measures .

The sand ,that will be desilted ,may be utilized for raising & strengthening of embankments to withstand higher flood of 12 lakhs cusecs against present design flood of 9 lakhs cusecs at delta head .

Removal of sand in river Mahanadi from Singitali to Musadiha

The right bank of river Mahanadi is scouring heavily from village Singitali to Musadiha for a length of 6.3 Km River Nuna has confluenced with river Mahanadi in between Musadiha and Singitali. Scouring at this location has become a regular phenomenon due to concentration of flow .The velocity of water in Nuna is more than the velocity of water in river Mahanadi there by thrusting the main flow line to the right side resulting in heavy scouring on the right side and depositing sand and silt on river bed at left side .The deposition on left side and scouring in right side has become a continuous process .

1.50 km of revetment & launching executed out of cyclone damage repair has again been completely damaged by wave dash & current .395m in worst affected portion have been repaired out of cyclone damage repair grant .

Unless some major remedial measures are taken it will scour further and the river may change its course endangering lives and property of nearby villages and Paradeep township area.

As a remedial measure it is suggested to remove the deposited sand and silt from the riverbed at the left side by dredging besides other flood control measures .

The sand & silt shall be used to raise ,strengthen and widen the embankments and filling the low lying areas .The dredging operation shall be conducted at a regular interval to facilitate & maintain the regime free flow condition .Also it is suggested to remove sand and silt form river mouth to mitigate the free flow discharge condition at the outfall point to sea .

Brahmani Basin

The river Brahmani is an interstate river which covers Bihar, Madhypradesh & Orissa .The river originates from Madhypradesh & Bihar in the name of 'Koel' & 'Sanhk' the two of its major tributaries & falls in Bay of Bengal in Orissa .The catchment area in Orissa is 22538 Sq.Km. out its total catchment area of 39291 Sq.Km.

River Brahmani enters into deltaic region at RD.315.00 Km. near Gadamadhupur Genapur in Orissa .Then after the river Kharsua takes off from Brahmani & again joins Brahmani at RD. 429.00 Km.River Birupa a tributary of Mahanadi joins Brahamani at RD. 372 Km on right .Baitarani a major river of Orissa joins Brahmani at RD 446 Km .The river Brahmani fall in Bay of Bengal at Rd 461.00 Km. near Dhamra .

A multipurpose dam at Rengali has been constructed across the river Brahmani at Rd 151.00 Km. to generate power ,control flood & provide irrigation .A barrage has been constructed at Rd. 182 Km. near Samal .

1. Removal of sand from the bed on right at Bankeshwar in the Brahmani River .

The river Brahmani takes a right angle turn at Bankeswar causing heavy scouring on its left bank .To prevent further scouring 7nos of spurs were constructed during the year 1974 .There was a slip in between spur No 5 & No 7 during Oct. & Nov. 1998 . A portion of the flood embankment was slipped into the river .There is also under current at the site. The depth of the water varies upto 17 meters .Preventive measure were taken during the year 1998-99 by providing launching and packing with crates .But the entire mass slipped into the river bed .Special repair of spur No. 4 & 5 was taken up during 1999-2000 .

Even then the left bank is vulnerable .The water way has been reduced due to sand casting on the upstream right side .The flow directly hits the left bank in between spur No. 4 to 7.

It is necessary to remove the sand from right side of the river to increase the water way ,besides other flood control works on left side .

2. Removal of sand on Brahmani left at Srirampur for protection at Kadamdandi

Kadamdandi is located on the right side of Brahmani river below Srirampur. There is sand casting in the middle of the river, hereby the left side flow directly hits the river bank at Kadamdandi causing severe scour to the village portion .Some houses have also been collapsed .5 nos spurs ,300 m of launching & packing were constructed .But the scouring continues .It is necessary to remove the sand form bed on left side to divert the current and increase the waterway in addition to the other flood control measures on right side .

Subarnrekha Basin

The river Subarnarekha is an inter-state river flowing through the state of Bihar ,West Bengal and Orissa originating form Chhotnagpur plateau near Ranchi at an elevation of about 690M above mean sea level .This river flows through the districts of Ranchi and Singhbhum in Bihar state for a length of 210 Km .After flowing 16 km as the inter state boundary in Bihar & Orissa ,it enters Midnapur in West Bengal and flows for a length of 56 Km. The river then flows as the inter state boundary of West Bengal and Orissa for a length of 10 Km. from Dantun to Laxmannath .

Finally it enters Orissa state and meets Bay of Bengal after flowing for 70 Km. within the district of Balasore .The flow remains confined within the river banks in the state of Bihar and also in part of West Bengal upto Basaraghat ,Beyond this point it starts spilling creating flood problems both in West Bengal and Orissa .

The catchment of the river at the out fall point into Bay of Bengal is 18,950 Sq.Km. state wise distribution is as fallows .

Bihar	....	13,59 Sq. Km.
West Bengal	....	2,16 Sq. Km.
Orissa	....	3,20 Sq. Km.

The river basin receives most of its rainfall during monsoon season mostly from the cyclonic storms originating in Bay of Bengal .

The uncontrolled flood discharge of river Subarnarekha has been considered as 7.50 lakhs cusecs which was the magnitude estimated in 1943 as per **Janardan Tripathy Committee Report** .

After construction of Kharkhai ,Ichha and Chandil Dam on its upstream , the computed flood discharges at Rajghat Railway bridge is taken as 4.50 lakhs cusec .As it is observed now the safe carrying capacity of the river is hardly 1.50 Lakh cusecs below Rajghat .

In course of time the river Subarnarekha has developed a very tortuous course with number of horse shoe bends and loops before joining the Bay of Bengal .The freeflow of flood gets retarded due to high tides creating drainage congestion and endangering the life and properties of local people Severe bank scouring takes place year after year causing loss of fertile cultivable land, houses, others properties and at some places the scouring has come very close to toe of the embankment .Dahamunda is one of these vulnerable locations .

Removal of silt at Dahamunda in river Subarnarekha

Along the entire course of the river Subernarekha on its left side, the scouring zone near the village Arunabhatti (Dahamunda) is the most vulnerable and alarming position .The nature of scouring of bank in this zone is very peculiar and critical. During the last seven years the river berm at this place has been washed out to the extent of 150 m to 200 m .Permanent structure like one school building one temple and one rice mill have been washed away due to erosion on bank caused due to flood .As per the present situation the river on the right side in being silted up with sand deposit rapidly and on the left side the riverbank is being scoured profusely creating an alarming and threatening situation for loss of homestead lands and a vast area of cultivable lands standing just adjacent to the river bank .

10 nos of low level spurs were constructed in this zone .3nos have been partially washed away with the higher turbulence of water and thus each year new study for the protection of the area in being thought of .During highest floods in the river from 6.8.97 to 9.8.97 ,low level spurs 8,9 to 10 has been damaged severely with breach on ulludakhalabadia T.R embankment on 12th January 1999 it was decided in 86th T.A.C. to construct a high level spur with a chada spur on upstream with a estimates cost of Rs. 2.42 crs. .Due to lack of fund full work could not be taken up ,but it was decided to take up in phases from 1999-2000 .But the problem of the area was not solved .

Mean while experts from Chennai IIT have visited the site and suggested removal of deposited sand on right side within 1.0m to 1.5m depth along with works suggested by TAC to save the area from flood damage .

Since work on the 2nd bridge on Subarnarekha started with 50m approaches on both sides ,the sand on the right side of vulnerable point may be transported and used in the approaches with same cost .As the Jaleshwar-

Batagram-Chandanshwar road work is going to start soon this sand chada may be kept as sand quarry for the road work .After the sand is removed the area can be saved from the high flood with no additional cost requirement .

Budhabalanga Basin

The Budhabalanga river originates from Similipal range in Maryurbhanja district of Orissa .The catchment area at its outfall is 4838 Sq.Km. .There are 9 tributares of this river out of which the prominent distributaries are Palapala ,Sone & Katara .The river traverses a length of 198.75 Km. before it meet the Bay of Bengal .

The river Kansabansa in a major river in Budhabalanga basin Gamei is a branch of river Kansabansa which has been silted up for which flood water is not being discharged smoothly .

Siltation problem in the river Gamei

The southern branch of river Kansabansa is named Gamei. This river is subjected to heavy flood & outflows as it is silted up to great extent .A greater part of its flood water enters through Ricket canal and then to river Matei which drains to Bay of Bengal .

After travelling a distance of about 4.70 km. directly the river Gamei falls inn the sea. Particulary the siltation is heavy from Chudamani to sea face which is obstructing the flow .Renovation for this portion is badly necessary from Chudamani to sea face .There are Nos of embankments of 16.50Km long on either side of the river .The embankments on either side should be strengthened by removed silt & sand .Necessary sluices are to be provided to drain out the country side water .

Siltation at off take points of rivers

Due to siltation the bed level of off taking rivers is at higher level than the bed level of parent rivers .During non-monsoon & summer season the water does not flow in these off taking rivers & flows in main river as discharge is less & bed of off take is higher than that of parent river. People residing in the side of these reaches face lot of difficulties to get water for drinking ,bathing & rabi cultivation Areach of river Birupa form offtake point of Genguti to Kumudaghat is one of such location .

(i) Desilting the river Birupa from offtake point of Geguti to Kumudaghat

Birupa river takes off form river Mahanadi on left at Chasapada. After travelling for a distance of 24 Kms the river branches to Genguti on left The bed level of river Genguti is 2 to 3 m lower than that of Birupa During non-monsoon all the water flows in the river Genguti making the river Birupa completely dry

.The people of village Laptua, Barahipur, Khetrapal, Chasakhanda, Sahapur, Arilo, Tribeniswar, Nurtang, Jalaarpur, Kuanpal ,Adammahesarpur ,Mulabasanta etc. on the side of the river Birupa in this portion face lot of difficulties in getting water .To avoid this difficulty it is necessary to desilt the river bed of Birupa & construct a divide wall at head of Genguti .The removed silt can be used to raise & widen the embankments on both sides of Birupa .The demand of the people of this locality has been published in Newspaper.

(ii) Flow in river Kani in non-monsoon season .

River Kani takes off from river Kharostrota Ex Brahmani near village Kantipur & falls to Kharosrota near Padanipal . The river kani has been silted up for which water does not flow in river Kani in non-monsoon period .People on the side of Kani dos not get water for drinking & lift irrigation purpose .Hence it is necessary to desilt the river Kani at its offtake point at Kantipur & in reaches where necessary

(iii) Desilting the outfall portion of Gochida Naslah falling into Sunarnrekha

Rain water from catchment of chitei Nallah in Balasore district do not flow smoothly to Subarnrekha as Gochidanallah from Gochida sluice to outfall has been silted up heavily .Drainage conjestion causes loss of khariff crop every year .It is necessary to remove the silt of Gochida nallah from Gochidasluice to outfall & at patches in upstream for free flow of rain water .

SILTATION IN RIVERS OF WEST BENGAL

INTRODUCTION

The State of West Bengal with snow white mountains at the north and with greenery, extending from foot hills to the sea on the south, is mixer of configuration varying from high areas to the plains. The Geographical area is about 88752 Square Kilometer out of which Area under forest is 11880 Sq. K.M. and flood prone area is 37660 sq.km. The area already protected is 22005 sq.km.

The State comprises of three distinct River basins namely Ganga Basin of area 74732 sq. km. Brahmaputra Basin of 11860 sq.km. and the Subernarekha Basin of area 216- sq.km.

The tributaries of the River Brahmaputra, namely Sankosh, Raidak, Teesta, Torsha and the Jaldhaka originate from hilly tracts of Bhutan/Sikkim in the sub Himalayas region and after passing through the State of West Bengal join with the River Brahmaputra, at different locations in Bangladesh.

The rest of the system with the exception of a few rivers of the Subarnarekha basin, belongs to the Ganga Basin. Among the tributaries the Mahananda, Punarbhaba, Atrai, join the River Ganga in the Bangladesh whereas the main tributaries to join the River Bhagirathi are Pagla Bansloi, Mayurakhi, Ajoy, Damodar, Darakeswar, Silabati and Kangsabati-Haldi.

The main rivers in the tidal zone are Ichamati, Raimongal, Tollys Nullah, Kultigong, Haroa, Gosaba, Piali, Thakuran, Saptamukhi, Matla, Buriganga etc.

RIVER SYSTEM

There are three categories of the river system namely large basins which is the Ganga basin having area 74732 Sq.km. medium river basin of the Brahmaputra basin of 11860 sq.km. and the Subernarekha Basin of area 2160 Sq.km.

The major river basin of the Ganga form 84% of the area of the State, whereas the medium river basins of the Brahmaputra and the Subernarekha form 16%.

The tributaries of the Brahmaputra basin namely Torsa, Jaldhaka and Teesta are forming medium river basins themselves whereas the tributaries of the River Ganga Basin, namely Mahananda, Dwaraka-Brahamani, Jalangi, Mayurakhi, Ajoy, Khari-Gangur-Ghea, Damodar,Dwarakeswar, Kangsabati, Silabati, Rupnarayan are forming medium river basins themselves.

TOPOGRAPHY

The State has topography of a wide range. The very steep slope of the Sub-Himalayan hilly tracts wherefrom the North Bengal rivers are originating, are the primary causes of the erosion. In the foothills, there is abrupt reduction in the slope and the Rivers considerably lose capacity to carry silt, when debouch to plain from the hills. This is how the erosion in the upstream hilly catchments and the silting in the downstream plains are taking place.

SOIL

The State has wide range of classification of its soil. In the northern districts of Cooch Behar, Darjeeling, Jalpaiguri, Uttar & Dakhin Dinajpur and Malda, the soil is mostly sandy and having no cohesion and as such it is prone to erosion. The District of Murshidabad is also no exception to it and the loss of large tracts of land in the above districts are regular phenomenon causing distress to the people from time immemorial.

CLIMATE

The river Ganga divides the State into two distinct parts which are more or less homogenious so far as the rainfall pattern is concerned. The northern part, which is Sub Himalayan West Bengal, is much more susceptible to heavy rains both in respect of quantity as well as in the frequency of occurring. The districts falling with this area of the high intensity rainfall varying from 2000 mm to 4000 mm, about 80% of the which is observed to occur during the monsoon. On an average, the three districts being Darjeeling, Coochbehar and Jalpaiguri get 114, 112 and 110 rainy days in a year.

VEGETABLE COVER

The area under forest in the State is only 13.3% of the total area. The State is densely populated and the density is highest in the country. In the latest census report, the density of population is 904 per sq.km. Due to lack of adequate scope of earning livelihood and for other various reasons, there has been extensive and indiscriminate destruction of forest, reducing the forest cover to prevent land slides and also reducing the layer of the fallen leaves and grassy surface to prevent erosion of the soil below.

TILLAGE PRACTICES

Adoption of unscientific shifting or 'jhoom' cultivation in the hilly areas has further aggravated the situation. In the districts of Purulia, Bankura, Birbhum and certain portion of Midnapur, there has been excessive exploitation of the land resources and irrational and reckless cultivation after cutting the forests leading to accelerate the soil erosion.

SILTATION

Out of two broadly accepted classifications of siltation, being Reservoir siltation and River bed siltation, certain study in the Kansabati and Mayurakshi reservoir were made and the finding of the said study is as below :

KANGSABATI RESERVOIR

1. Dead storage loss in 36 years = 27.96%
2. Live storage loss in 36 years = 7.38%
3. Total storage loss in 36 years = 10.06%

   The Loss Index is 182.69 Acres-ft/year/100 sq miles (8.71 Hac mt/year/100 sq km)

   Sedimentation Index is 189.69 Acre-Ft/Year/100 Sq. Miles (9.00 Hecter-Meter/Year/100 Sq K.M.)

MAYURAKSHI RESERVOIR

1. Dead storage loss in 41 years = 47.76%
2. Live storage loss in 41 years = 11.13%
3. Total storage loss in 41 years = 15.23%

   The Loss Index is 255 Acre-ft /year/100 Sq Miles (12.75 Hecter-Meter/ Year/100 Sq Km)

   Sedimentation Index is 265 Acre-ft /year/100 Sq Miles (13.25 Hecter-Meter/Year/100 Sq. Km)

The comparative Study of the Kangsabati Reservoir was conducted for the period from 1965 to 2001 and that for the Mayurakshi Reservoir was conducted for the period from 1954 to 1995. The details of the said study may be seen in separate charts enclosed herewith.

There are a few hundred rivers in the State of West Bengal and a large number of them are having either international or interstate characteristics. The river bed siltation is normally a very slow process and usually not monitored on any regular basis. Further the process of silting starts from its very source and any study in any intermediate region without having any scope to take up the study for the entire length of the River, will be a fruitless exercise.

VIEWS OF WEST BENGAL

The following are the causes of the siltation in the rivers of West Bengal :

1. Indiscriminate destruction of the forest cover.
2. Unscientific extraction of mineral especially dolomite in the areas of Bhutan in the hill slopes.
3. Shifting (Jhoom) cultivation.
4. Land slide for steep hilly slopes.

5. High Intensity of Rainfall in the order of 3200 mm (and above), occurring in the monsoon months.
6. Soil without any cohesion to resist erosion.
7. Inadequate waterway under the Railway Bridges.

In order to minimize the siltation the following suggestions may be examined :

1. Gradual stoppage of indiscriminate destruction of the forest cover and grassy fields.
2. Stoppage of unscientific extraction of minerals especially Dolomite through the negotiation & interactions with boarder Governments by constituting Joint River Commission (JRC).
3. Gradual stoppage of shifting (Jhoom) cultivation.
4. Treatment of hilly catchments by construction of check dams, flood storage dams etc.
5. Aforestation on hill slopes to save soil mantle and to reduce the possibility and recurrence of the land slides.

The silting problem in the State of West Bengal is not only having a very big dimension but also has international and interstate characteristics leading to operational responsibility on the Government of India through constitution of the JRC and referring the matter for preparation of comprehensive Master Plan and time bound Action Plan thereof.

The drive so far taken by the Government of India in this respect is quite praiseworthy and welcome and the progress in this direction followed by certain positive activities will be beneficial to the common people of West Bengal.

A REPORT ON THE MATTER OF DESILTATION OF RIVER BRAHMAPUTRA

The fact is that the river Brahmaputra is one of the most formidable rivers in the world, it being a braided channel in its trait with the perpetual changes of its geometry. The Brahmaputra valley in India is mainly an alluvial plain and the impetuous and snowfed river while debouching from the Himalayas hardly gets any resistance and as such constantly curves out new channels and erode its banks made of friable soil the composition of which is silt and sand, the percentage of clay being only 7% throughout its journey of 918 km in India except Guwahati and Tezpur before it outfalls to the Bay of Bengal. The 'shoals' that form in the mid river are the process of deposition of silt and sand and continues to disappear and reappear vacillating in between north and south bank. The shoals consists of sand, predominantly the course sand up to a depth of 6.5 metres and so these are easily susceptible to erosion at low velocities. The bed material were observed to be silty loam to sand with clay content of about 5% only.

In fact, the factor on which depend the depths for navigation in an alluvial river are velocity, flood slopes, meander, channel configuration under local conditions, difference in high and low water levels, difference in high and low discharges, sediment load movement, various sizes of sediment load, etc. But due to lack of indepth study of the sediment load (bed load and suspended load), the sediment transport characteristics of the river is yet to be determined. It is the bed load which is responsible for the change of channel geometry as the suspended load is the advanced stage of bed load movement intersified by eddies. The equilibrium scour of the channel section is not expected to attain because of continuous movement of the bed particles with the increase of velocity. It is the greater Tractive force than the frictional resistance between sand particles bed load is forced to start the process of siltation. The stability of the river section has, therefore, been found to be disturbed due to bed scouring and bank erosion in different stages and inflow conditions due to the phenomenon which still remains to be unpredictable. The most significant part of it is that the substantial part of the scour hole gets filled up within no time.

Degeneration of soils due to deforestation in the upper catchment areas accelerate the problems thereby enhancing the erosional capabilities of the rivers.

The selsmo sediments are partially deposited along the bed and banks of the river and partially carried to the sea. Besides the seismo sediments after the severe earthquake in Assam in the year 1950 that have still been moving under gravity, the sediment loads duė to frequent seismic disturbances of low magnitude have been responsible for changing the channel geometry every now and then.

The sediment problem in the river Brahmaputra, pose a serious threat to socio-econoimic structure of the State with its erosive havoc almost every year.

But the flood problem created due to climatologically factors is enhanced significantly due to sediment problems. The flood control department, in the mid seventies, ventured dredging of the river bed in selected reaches for its channelisation in a definite course which could have paved the way for navigational aspect also. But the gigantic river did not yield to such operation and continued its behavioral phenomenon due to which the channels that were dredged got filled up after the next year floods. Hence the experiment proved to be futile. Even the Board of consultants in their emergent meeting in the year 1979 at Guwahati discussed the ill effect of dredging. The minutes of discussion are as follows :-

"The Board of consultants arrived at the conclusion that taking into account the dredging operations carried out so far, it is not worthwhile to retain the dredgers for use in the main Brahmaputra river or the tributaries."

The minutes of discussion of the 31st meeting of the Board of Consultants held at Guwahati in May, 1981 are also very specific as below :-

Moreover, it is very costly. Once the entire river system is trained and stabilized by various other methods, the dredging may be used for minimum purpose. But in the initial stage of river training or bank stabilization it will not serve much purpose. Even in the year October, 1991, the Technical Advisory Committee was not in favour of dredging operation. But suggested that "efforts may be taken to channelise each tributary from foot hills to outfall giving priority to the embanked rivers".

In the context of above scenario in respect of hydrological as well as geomorphological aspect it is an established fact that some strategy need to evolved so as to contain the silt load to a reasonable extent in the upper catchment areas from entering the river rather than concentrating on the preposterous proposition of removing the deposited silt from the river bed. This has to be considered alongwith the flood problems in these areas.

In order to meet this challenge the principal emphasis to be laid on watershed areas ranging from 10 Sq. km to even 250 sq. km. And for that purpose watershed management programme need to be launched with a definite objective for judicious utilization of land and water to ensure prevention and modernization of flood with scientific environmental management. It is a long term perspective planning need to be undertaken by the Engineers, Technocrats, Scientists, Sociologists, Economists under integrated multidisciplinary approach concerning to various Departments, viz. – Flood Control, Irrigation, Agriculture, Horticulture, Soil Conservation, Social Forestry, Pisciculture and even floriculture, P.W.D. (Roads) and Power.

To achieve the objective, it is of utmost necessity to go for specific location need based survey in respect of characteristics of the soil, water availability, sediment problem, geological structure of the land, ecology, topography and slope of the land, land use pattern, shape and size of the watershed, grazing practice and the likes. Also the agricultural system and agricultural probability along with demographic status of the locality of the specific area including its adjoining areas required to be studied.

After identifying the problems in each field as per characteristics of the watershed areas the flood damage reduction measures, viz., various Gully Control Measures, small/medium detention basins, detention dams, bank protection works, afforestation, grassland management, contour bunding and farming, channel improvement, Tarracing, etc. should be undertaken. In addition to the above, the imperative need would be channelising the waterway in a definite direction with bank stabilization works on both banks of the river phasewise so as to forcing the bed particles continue the process of siltation with increased component bottom velocity.

However, to achieve the above objective, a Committee to be named as Watershed Management Committee need to formed to chalk out the detailed plan programme accordingly.

BRIEF NOTE ON SILTATION PROBLEM IN THE RIVERS OF ASSAM

The river Brahmaputra after traversing a distance of 1625 km. in Tibet enters into India in the state of Arunachal Pradesh and thereafter flows 218 km. in the Indian Territory before it falls down to the Bay of Bengal through Bangladesh for a distance of 354 km.

With the perpetual changes in its behaviour the formidable river is a braided channel. The shoals that form in the mid-river and due to the process of deposition of silt and sand and continues to disappear and reappear vacillating in between North and South bank. The bed materials from Dibrugarh to Goalpara have been observed to be silty loam to sand without clay content except at Dibrugarh (only 5%). The friable bank materials contain silt and sand, the percentage of clay being only 7%.

Due to severe earthquake in Assam in the year 1950, the seismo sediments have still been moving under gravity due to which the changes of its course have been observed. Moreover, the sediment load due to frequent seismic disturbances of low magnitude have been moving along the flow.

Ecological problem due to environmental disturbances have serious impact on hydrology. Degeneration of soils due to indiscriminate massive deforestation in the upper catchment areas by the unscrupulous traders accelerate the problems thereby enhancing the erosional capabilities of the rivers. Many of the rivers, therefore, on debouching into the plains, lose much of their carrying capacity and the sediments deposit in the riverbeds causing alluvial form. The siltation problems in the river Brahmaputra and its North bank tributaries have been the cause of concern whereas the South bank tributaries have graded course and a sluggish meandering course in most of the journey. General scour of the riverbed take place due to the continuous process of rise and fall of water level with the transportation and deposition of silt. Equilibrium scour in not expected to be achieved because the flood is not sustained for a longer period. The sediment load of the Brahmaputra at Pandu has been observed to be 1.59 acre ft/sq. mile of the catchment area. On the other hand, the river Barak from Lakhipur to Bhanga while traversing a distance of 150 km. within the state of Assam, on the alluvial plain, causes bank erosion at places and continues to flow with deposition of silt on the river bed alongwith the problem of sloughening which facilitates the river bank to slide down due to underground seepage water from country side ponds, abandoned course of river etc.

To counter-act the siltation problem in the river Brahmaputra, the State Flood Control Department, endeavoured with Dredging operation of the river bed in mid seventies; but this appears to be futile exercise as the excavated channel was filled up during the next flood season. Hence the Board of Consultants in their emergent meeting at Guwahati in the year 1979 discussed the ill effect of dredging and they arrived at a conclusion to discourage dredging operation and said that it is not worthwhile to retain the dredgers for use either in Brahmaputra or in its tributaries. Again in May, 1981 they said "..... Moreover it is very costly. Once the entire river system is trained and stabilized by various methods, the dredging may be used for minimum purpose ; but discouraged dreding in the initial stage." Even in October, 1982 the Technical Advisory Committee was not in favour of dredging operation. But suggested that 'efforts may be taken to channelise its tributary from foot hills to outfall giving priority to the embanked rivers'.

It is, therefore, necessary to strike at the root cause of the problem. Watershed Management, in this aspect, play a vital role as a long-term area development technique for reduction of erosion. So, sediment control at the upper catchment areas with judicious use of land and water through watershed management is of prime importance both in Brahmaputra as well as Barak valley. Afforestation of the denuded forest area, installation of gully control and sloughening control structures, development of improved grass land, small and medium detention dams, bank protection works are the measured to be adopted.

PROBLEMS OF SILTING IN INDIAN RIVERS WITH SPECIFIC REFERENCE TO BIHAR

INTRODUCTION :

The soil erosion and sediment yield problems are important for India primarily because of varying topographical and geological conditions, pressure of human and animal population on land resources and because of small land holdings. This is further aggravated by improper land use and faulty land management practices being adopted in the upland watershed. The situation is more alarming in case of Bihar as major watershed area of its basins lies in Nepal. The main factors affecting sediment yield are hydrology, nature of catchment, soil, land use cover and management practices of a watershed.

Studies carried out in India indicate that land use pattern is fast changing in the country. These is an urgent need to carryout studies of the effect of this land use change on erosion an subsequent sediment yield, as any long term or short term change in the land use definitely influences hydrological process in the watershed. These influences are more severe if the top fertile soil is eroded.

The studies of sediment yield in our country have been confined to some reservoirs, and small watersheds. Their results can be taken to be suggestive and indicative and cannot be extrapolated to large catchment. There is a need that our study should not be limited only to measure the incoming sediments but also include suggestive measures to retard it.

2.0 BASINS OF BIHAR

Hydo-meteorologically, India is divided in 26 sub-zons by the Central Water Commission. Bihar territory fully lies in sub-zone1(g); i.e., lower Ganga Basin. The undivided Bihar had been sub divided at micro-level by State Hydrology Cell in 22 sub-zones, out of which 6 are now in Jharkhand State. All rivers of North Bihar, namely Kosi, Gandak, Bagmati, Kamla-Balan, Adhwara groups and Mahananda have their origin in the Himalays in Nepal. These rivers have about 61% of their catchment area in Nepal and Tibet region. These rivers with very steep slope and enormous gorges flow through the geologically young Himalayan mountain region containing sedimentary rock layers. During the course of the river flows, these result in the carriage of very heavy silt load during the monsoon season. The problem of silt load is further accentuated by the large scale deforestation in the upper catchment region of these rivers. When these rivers debauch into the plains of Nórth Bihar, it causes deposition of sediment in the river beds, consequently raising the river bed and reducing the carrying capacity of the rives and the canal systems. The rivers originating from high altitudes and then flowing through one of the flattest terrain and poor out-fall conditions-this uniqueness of the topographical condition may be summarised as the rootcause of the problem. For reference, slope of some of the important basins are noted below :

Name of river	Reach	Slope in m/km
KOSI	0 to 42 KM/Nepal	1.4
	42 KM to 68 KM/Nepal	0.716
	68 KM to 134 KM	0.45
	134 KM to 310 KM	0.11
KAMALA BALAN	Upto Indo-Nepal Border	3.4
	Jainagar & below	0.2
GANDAK	Upto Valmikinagar/Nepal	5.7
	Valmikinagarto Chhitoni Railway Station	0.3

3.0 SPECIFIC PROBLEM

Some of the hydrologic and hydraulic problems are described here in brief for illustration.

3.1 Shifting and Erosion of Kosi :

The Kosi River is notorious for its capricious nature. It carries with it an enormous load of sand which it is unable to transport and consequently unloads into the main drainage channel, and the Ganga River. In the process of building up an island delta, it has shifted over 112.6 KM (70 miles) from east to west during the period from 1736 to 1964. In this movement, about 7770 sq.km.(3000 sq.miles) of land in Bihar and approximately 1294.99 sq.km. (500 sq. miles) in Nepal have been laid waste as a result of sand deposition. In the course of shifting, many towns and villages were wiped out and heavy losses of property, cattle, and even human lives were inflicted.

By and large, the geology of the Kosi catchment is showing unstable nature, which is susceptible to heavy wear and tear, bringing increasing sediment loads especially compared to the southern non-Himalayan rivers, which are fairly more stable, because of hard basaltic or granite formation.

3.2 Embankment over topping

In the river Gandak, Champaran embankment built on the left bank of river has faced spilling of river water during the last monsoon. It is worth to be noted that the discharge observed downstream of Gandak Barrage at Valmikinagar was 4,70,500 cusec on 1.8.2001, which was lesser compared to the maximum observed apparent that even in lesser discharg, the Champaran embankment faced the problem of spilling of river water, causing breaches at different places.

The studies made suggest that during the year 1978 to 2001, the river bed has silted up approximately 1.83m.

In the case of Kamla Balan, the siltation has been so severe that the general Ground level on the river side of the embankment has aggraded to an extent that it is approximately 4 metres above the country-side NSL and thus rendering all the sluice out country side water into the river.

River Kosi has severely meandered due to aggradation o river bed by silt deposition. The river in the upstrem of the Kosi Barrage is flowing along the left embankment and is causing severe erosion of the spurs. In the down-stream of the barrage, the river course has shifted towards right side and the left bank of the Western Kosi Main Canal left bank is facing severe erosion from 0.00 km to 4.5 km. Besides this, the main Western Embankment along with spurs up to 5.3 km had been under severe erosion. The morphological change in the river course is now threatening the entire Western Kosi Canal System as well as the infrastructure built-up for protection is the region.

3.3 Flood forecasting:

Flood hydrograph is a composite response of catchment, channel and precipitation. However, all these are variable in time and space, but the variation in precipitation is more prominent in terms of areal distribution, intensity, duration and depth. Hence, precipitation component is to be assessed closely as a true sense of flood forecasting.

As narrated above that major watershed of the North Bihar rivers lie in Nepal. For example we may take the case of Gandak sub-basin. The river Gandak drains a total catchment area of 46,300 sq.km, out of which only 6620 sq.km. lies in India and rest in Nepal and Tibet. A considerable portion of the catchment in Nepal and Tibet falls in the glacial region of Himalayas and so the Gandak is a snow-fed river and perennial. One sixth of its catchment lying in Nepal and Tibet remains under snow cover all round the year. The catchment area up to Valmikinagar (West Champaran district, Bihar, where Gandak Barrage is situated) is hilly and the rest in India forms part of gangetic plains.

According to the norms of the IMD, 92 raingauge stations are required in the drainage area of river Gandak. 15 such stations are required in lower catchment in India and rest 77 stations are required in Nepal and Tibet, but presently there are only 7 rainguage stations and we are getting rainfall data from Bhairwa and Pokhra only.

For want of sufficient data of rainfall, Central Water Commission is unable to make real time, flood forecast at Valmikinagar Barrage site. As we are aware that more discharge would carry more silt, so in absence of real time forecast for discharge, it is unpredictable to know the silt quantity also. This leads to inappropriate operation of Barrage gates, which may b a majo cause of silt deposition near the structure. Similar is the case in Kowi-sub-basin also.

4.0 SUGGESTIVE MEASURES:

There are some suggestive measures which can minimise the problem of siltation. As stated above, the major water-shed of almost all sub-basins of North Bihar are lyig in Nepal and as such measures are to be taken either by the HMG Nepal or with their consent. The suggested measures are noted below :

- Soil conservation
- Reservoirs with flood cushion in the upper catchments lying in Nepal
- Afforestations
- Establishing adequate rain-fall & discharge observation stations in Nepal

The matter needs to be accorded the highest priority by the Govt. of India who may like to deliberate with HMG Nepal and take the remedial measures in right earnest.

5.0 ANNEXURES

The following maps showing the rivers system of BIHAR and the regime plan of Kosi river are appended :

i) Basin Map
ii) Kosi Map near Barrage

SILTATION IN RIVER BRAHMAPUTRA

1.0 INTRODUCTION

The Brahmaputra is one of the largest rivers of the world having catchment areas in Tibet, Bhutan, India and Bangladesh. The average annual flow of the Brahmaputra has been estimated to be 61.40 m ham at Bahadurabad(Bangladesh) near its outfall into the bay of Bengal.

Of the rivers in the world, which transport heavy sediment load, the Brahmaputra, has the unenviable record of occupying the third position, indicating the severity of soil erosion in the basin. The observed average sediment yield of the river is about 527 million Tonnes / year (1978 to 1991). The ill effects of this severe soil erosion is most prominent in its traverse through India, particularly the Assam valley, where the Brahmaputra, burdened with heavy sediment load attacks the banks. This has been the nature of the river since ages and during this period it has eroded so much of fertile land that flood plains of the river covers almost 40 km of the 80 km wide narrow Assam valley.

1.1 The Sub-basin

The Brahrmaputra sub-basin is a major part of the Ganga-Brahmaputra - Meghna basin and extends over an area of nearly 580,000 sq. km. It covers huge area in Tibet, India, Bhutan and Bangladesh.

In India, the Brahmaputra sub-basin lies in the states of Arunachal Pradesh, Assam, Nagaland, Meghalaya, Sikkim and West Bengal. The portion lying in Arunachal Pradesh, Nagaland, Meghalaya and Sikkim is hilly. In Assam and West Bengal, the catchments consist of hills, forest, tea gardens and fertile plains.

1.2 The River System

The river originates from Mansarowar at about 5000m above the MSL. After traveling 1625 km in Tibet, the river flows for 918 km in India before entering Bangladesh. The river is called the Tsansgpo In Tibet and the Siang or Dehang in Arunachal Pradesh. The Siang or Dehang travels about 52 km from Pasighat, before two major rivers namely the Debang and the Lohit join it. From the tri-junction, the river is called the Brahmaputra. A few kilometers downstream of Dhubri, the river enters Bangaldesh and after flowing for 337 km it joins the Ganga at Golundo in Bangladesh.

Throughout its course in India, the river is braided with some well defined nodal points, iwhere the river width is narrow and is restricted within stable banks. All along the course in the valley of Assam, abandoned wet lands and back swamps are common.

Average dry season discharge at Pandu 4,420 cumecs.

E. Normal annual rainfall

Ranges	between 2,125 mm in Kamrup district of. Assam and 4,142 mm in Tirap district of Arunachal Pradesh.

The longitudinal section of the Brahmaputra is shown in Plate No.1. Large drop in the river just after entering India is particularly noticeable.

1.4 The Tributaries of the Brahmaputra

The Brahmaputra in India has about 20 important tributaries on the North bank and about 13 important tributaries on the South bank. The North bank tributaries come from higher rainfall region and pass through fragile Himalayan reaches with steep slopes and they carry heavier sediment of course size and are braided over major portion of the lengths. The south bank tributaries pass through relatively stable reaches with flat slopes and carry lower sediment load and of fine size.

The annual contributions of yields of the different tributaries are shown in Plate No.II.

1.5 River Reaches

The Master Plan of Brahmaputra Basin has divided the main river into seven reaches.

These are:-

i) From source in Tibet to Tibet- Indoborder.

ii) Tibet- Indoborder to Kobo- In this reach the river is known as Siang or Dihing and flows in an almost southerly direction though steep mountainous gorges before reaching Pasighat. From Pasighat, the Dihang flows for another 52 km. before it is joined by the Lohit and the Dibang rivers. The combined flow of these three rivers forms the Brahmaputra at Kobo.

iii) Kobo to Dihingmukh- From Kobo, the river flows southward initially and then westward upto outfall of the tributary Dibru and finally south – westward upto Dihingmukh.

iv) Dihingmukh to Dhansirimukh- In this reach the river becomes a sea of water which covers a width of 15 km. In the upper portion. The biggest river island Majuli of Jorhat district lies in this reach.

v) Dhansirimukh to Pandu- In this reach the river flows in alluvial valley with rock outcrops at some points. The bed and bank materials are easily erodible and bank erosion is conspicuous - The river has braided channels except at Pandu

vi) Pandu to Dhubri- The river in this reach has reduced width at some sections with rock outcrop and flows in braided channels between erodible alluvial banks. During floods, the river has a maximum width of 19 km.

vii) Dhubri to Outfall - From Dhubri it traverses nearly 337 km to join the Ganga (also called the Padma) at Golundo in Bangladesh.

Sixty five cross-sections of the Brahmaputra river spanning over a length of 600 km are available for the years 1957; 1971, 1981 and 1989. The cross sections have been marked in the field by permanent mounds. The locations of the cross-sections have been shown in Plate No.III.

1.6 Drainage Composition

The north, bank tributaries show in general a parallel drainage pattern and the south bank tributaries while keeping the parallel pattern show signs of dendritic configuration. The drainage density(length of channels per unit area of catchment) is rather low and varies from 0.07 to 0.17 km. per km. The other characteristics of this area do not show similarity with average values ohtained elsewhere

1.7 Geology

On the northern side of Brahmaputra Valley, the formations generally comprise alluvial plain abutting against the Siwalik range of the Himalayas. In the Lohit area on extreme eastern side, the Siwalik belts are not exposed and the alluvial deposits are by and large directly abutting against the metasediments followed by rock outcrops of different characters. It is'however ,felt that the basement of the entire basin is made up of the type of metamorphities of Shillong Plateau and Mikir Hills.

A major part of the Brahmaputra and Surma valleys is covered by recent alluvial deposits grouped as newer or low level alluvium comprising clay, sand, silt and shingle. The formation varies in thickness from 200 m to 300m,

1.8 Landslides

Landslides are natural phenomena of degradation in any of the hilly terrains where rainfall is high. The process is accelerated by earthquakes, torrential rains, toe cutting of hill slopes by streams and rivers. Heavy rains often loosen the soil and the soft and highly splintery and friable rocks in the young Himalayan ranges of the basin.

1.9 Seismicity

The main tectonic features which have a bearing on the seismicity of the basin are, the main boundary fault and other thrusts in the Arunachal Himalayas, Dawki fault, Chidrang fault, Dhubri tear fault, Madhopur fault, Naga thrust and Lohit thrust.

Earthquakes occur at random and there is always an uncertainty about their time of occurrence, location and intensity of shocks. Between 1920 and 1980 as many as 455 earthquakes of magnitude higher than 5 on the Richer scale were recorded in the region, an average of about eight per year, magnitude-wise their distribution is :-

Magnitude (Richter)	Number of occurrence
5 to 6	270
6 to 7	167
7 to 8	15
8 and above	3
Total	**455**

Beyond 1980, upto 1988, earthquakes of magnitude higher than 5.5 on the Richter Scale were recorded in the NE Region as noted from IMD Data, Magnitude-wise their distribution is :-

Magnitude (Richter)	No. of occurrance
5.5 to 6	6
6 to 7	2
7 to 8	1
8 and above	NIL
Total	**9**

2.0 EXTENT OF THE PROBLEM

2.1 Water and Sediment Yield :-

The average annual water yield of Brahmaputra at Pancharatna considering the year 1971 to 1991 is 50 M ha m (as compared to 61.4 M ha at Bahadurabad, Bangladesh). The drainage area up to Pancharatna being 5,33,000 km, the runoff works out to 94 cm compared to 66 cm at Bahadurabad. The observed sediment yield (allowing for 15% Bed load) from 1978 to 1991 is

527 million tonnes as per year, which works out to 990 tonnes/sq.km (as compared to 1128 tonnes/sq.km at Bahadurabad). It is interesting to compare these with corresponding figures for other rivers of the world. Table I shows the sediment yield and annual water yield of some of the world's rivers. It can be seen that the sediment yield value is relatively high and compares well with sediment yield values in China,Peru,& U.S.A. Further, it compares reasonably well with reported sediment yield of 1128 tons/km/yr. in Bangladesh in Ganga/Brahmaputra basin.

TABLE – 1

ANNUAL WATER AND SEDIMENT YIELD OF WORLD'S RIVERS, BY SEDIMENT RIVERS, BY SEDIMENT YIELD

S.No	Continent	Country	River	Drainage Area (m. sq.km.)	Runoff (cm)	Sediment (t/sq.km.)
1	ASIA	CHINA	HAIHO	0.050	4	1620
2	ASIA	CHINA	DALING	0.020	5	1800
3	ASIA	CHINA	YELLOW	0.770	6	1403
4	S.AMERICA	PERU	CHIRA	0.020	25	2000
5	ASIA	CHINA	LIAOHE	0.170	4	241
6	N.AMERICA	MEXICO	COLORADO	0.640	3	211
7	AFRICA	MOZAM BIQUE	LIMPOPO	0.410	1	80
8	AFRICA	EGYPT	NILE	2960	1	38
9	ASIA	INDIA	DAMODAR	0.020	50	1400
10	N.AMERICA	USA	BRAZOS	0.110	6	145
11	AFRICA	TANZAN IA	RUFIJI	0.180	5	94
12	ASIA	PAKISTA N	INDUS	0.970	25	454
13	N.AMERICA	USA	COPPER	0.060	65	1167
14	ASIA	BANGLA DESH	GANGA/ BRAHMAPUT RA	1.480	66	1128
15	AFRICA	S.AFRIC A	ORANGE	1.020	1	17
16	OCEANIA	AUSTRA LIA	MURRAY	1.060	2	28
17	ASIA	IRAQ	TIGRIS	1.050	4	50
18	ASIA	INDIA	GODAVARI	0.310	27	310
19	ASIA	VIETNA M	HUNGHO.	0.210	103	1083
20	OCEANIA	NEW GUINEA	PURARI	0.031	248	2581

The Brahmaputra is a snow fed perennial river which gets flood from May to September. Over 80% of the flow and over 95% of the sediment contribution takes place during this period.

The maximum annual suspended sediment load at Pandu has been 36,609 ham in 1958 and the minimum 1487 ham in 1973.

The Siang(Dehang), Debang and the Lohit carry the highest sediment load Over 70% of the annual average silt load at Pandu is, contributed by these three rivers.

Of the north bank tributaries, the Subansiri, the Jiadhol the jia Bharelli, the Manas and the Sankosh carry high sediment load. The remaining tributaries carry comparatively low sediment load.

The South bank tributaries carry relatively low sediment load. Amongst these, the Buridihing carry the highest while the Kopili, the Dhansiri(South) and the Desang also carry significant load.

The approximate average annual rate for the first 50 years and for 100 years of the major tributaries of the Brahmaputra is as under:-

Name of tributaries	**50 years(ham/sq.km.)**	**100 years (Ham/sq km)**
Siang(Dehang)	0.048	0.044
Subansiri	0.113	0.106
Lohit	0.120	0.110
Deabang	0.126	0.115
Jia Bhorelli	0.121	0.111

3.0 SHIFTING OF RIVER CHANNELS

The Brahmaputra river has braided channels in most of its traverse through the plains of Assam and has a width varying from 3 km to 19km.

3.1 Braiding and Shifting Island

There is large seasonal variation in the flows of the briver and its tributaries. The river currents frequently change direction due to local islands, which in turn induces deposition at these islands. The large volume of fine sediment *(of* fine material) induces rapid silting with the change in velocity. Any change in current direction at some upstream location leads to erosion of the existing islands and formation of new islands further downstream. Such channel changes and shifting islands lead to significant changes in the braiding pattern even during a single flood event.

3.2 Shifting Mouths of Tributaries

The general tendency of the river to shift southwards causes erosion along the south bank.. The tributaries on the south bank have flatter slopes and even a small southward erosion causes considerable shifting of the confluence of the tributaries in the upstream direction.. This also causes erosion of the tributary embankments at the junction with the main river and formation of sandbars at the

The process of shifting of the river has been continuing through ages. The river has a tendency to shift laterally, as can be observed clearly from the changes in the outfalls of its various tributaries, particularlv in the South bank The South bank tributaries near their outfalls normally flow parallely to the Brahmaputra. The lateral movement of the river in Southerly direction has the effect of shifting outfalls of these tributaries eastwards. For instance the confluence of Dibru and the Brahmaputra used to be about 6.5 km downstream of Dibrugarh town in the later part of the last century. Now it is about 13 km upstream of the town.

Because of mild slopes near the conflucnce, some of the north bank tributaries form submarine deltas which appear to contribute to the south ward shifting of the river.

4.0 EFFECT OF SILTATION IN THE RIVER REGIME

Brahmaputra river has an extensive Himalayan catchment with steep hill slopes and fragile nature of rocks which is subjected to heavy rainfall. Additional factor accentuating the sediment yield is the seismicity. The basin happens to be a region prone to frequent earthquake after which the sediment load of the river is substantially increased. Earthquakes are unpredictable and can be very violent and can cause inflow of enormous quantity od sediment into the river rather abruptly causing dratic changes in the ricer regime and bed levels.

Plate-IV. shows the yearly low water and high water levels of the Brahmaputra at Dibrugarh for the period 1913 till 1990 specially indicating the years of strong and mild earthquakes. The figure clearly indicates the effect of earthquakes of 1918,1923, 1947, and 1950 on rise of water levels of the river. The low water level rose by as much as 3.4 m during 1947 to 1951 and thereafter remained nearly steady. After the severe earthquake of 1930, there. was however no rise in water level. This has been attributed to the fact that the epicenter of the earthquake was about 480 km downstream of Dibrugarh and as such had marginal effects on the sediment yield from the contributory basin areas.

In absence of severe earthquakes, the trend for bed level changes follow a different pattern as revealed for the period subsequent to 1957. Study for this period is made on the basis of cross sections taken from time to time.

As indicated earlier, sixty five cross-sections of the Brahmaputra river spanning over a length of 600 km are available for the years 1957, 1971, 1981 and 1989.

For the purpose of comparison it was found necessary to add marginal end correction to the cross sections to bring them to a comparable length and to introduce consistency in the data.

The cross sectional area of flow in each cross section has been computed with a small computer program neglecting areas of chars and islands which were above high flood level The high flood levels of 100 year frequency were adopted for the different cross-sections. The lengths of cross sectio,ns (denoting the width of the river) vary considerably from one cross section to allother. Since it is difiicult to locate the centre line or any other point in the cross sections of different years, the comparison of the widths of the river along its length has been made assuming one bank to be straight and attributing the entire variation of width to the other bank. The comparison may be seen in Plate-V. The width of the river varies from about 3000m to 18,000m.

The variation of area of flow at different cross sections along the Brahmaputra river is shown in Plate-VI. There is significant variation in the area of flow from one year to another indicating deposition or erosion at each of the cross sections.

The extent of the volume of deposition and erosion/scour between the cross sections (taking the difference in flow areas at each cross section) have been computed for different reaches of the river and are given in Table II

A comparison from 1957 to 1971 shows that there is no significant deposition or scour over the entire length of the river under consideration. However, the scouring and deposition in different reaches is not uniform. During this period, aggradations of about 6.35 cm per year and a scour of 6.85 cm per year appears to have taken place at different locations. Beyond 1971, scour is however more marked and in the period from 1971 to 1977 scour of the order of 10.92 cm per year has been noted. In the period 1977 to 1981 scour of about 3.7 cm per year is noticed. However for the period 1981 to 1989 aggradations of 2.5 cm per year is noticed. There are considerahle aggradations in the head reaches upstream of Dibrugarh at the rate of 16.85 cm per year. Considering the whole period of 1957 to 1989 for which cross sections are available, a scour of 1.92 cm per year is noticed almost in the entire length of the river except for aggradations in the upper most reaches of the river.

Thus it is summarized that large quantities of sediment which entered the Brahmaputra river system at its upstream end, after the 1950 earthquake moved downstream till about 1971 and hence deposition is indicated during this period.

After 1971 the sediment is eroded from the bed and the bed has gone down at a decreasing rate upto 1981 and has started aggradations in the period 1981 to 1988-89. The high floods of 1987 and 1988 brought down heavy sediment load. This resulted in sediment deposition and 1.35 m of aggradations in Dibrugarh reach has been noticed Thus aggradations and degradation in a reach are not steady and continuous phenomenon but are event specific and temporal. .

If the above inference drawn from the analysis of cross sectional data is correct it is at great variance with the general and often repeated view expressed that the river bed of Brahmaputra is continually rising. It is felt that more authentic data on continuing basis need to be collected and made available for further analysis to come to a definite conclusion in this regard.

From the average depth of flow at each cross section for each year for which the cross sections are available, the bed levels have been computed and these are marked in Plate- VII as a variation of the level from 1957. The examination of these plotting also indicates that the average depth has increased 'in most of the reaches

5.0 DIBRUGARH PROTECTION WORKS-A CASE STUDY

The recurrent erosion particularly after the 1950 earthquake has caused irrepairable damage to many important places along the rivcr bank in addition to other cultivable and homestead lands. The Sadiya town, on the confluence of the Dibang and Lohit, was completely eroded away in 1953. There was severe erosion in Dibrugarh in 1953-54. Major portion of the Palasbari town downstream of Guwahati, was lost to erosion during the same period. Erosion was also severe at places like Majuli, Biswanath, Laopara, Haulighat-Mukalmua, Bohori and Dhubri on the north bank and Mothola, Oakland. Desangmukh ,Kokilamllkh-Nematighat and Moriahola, Alikash,Goalpara and Kakiraganj-South Salmara area on the south bank at different periods. In view of the severity of the erosion and consequent widespread damages, anti-erosion measures had to be taken up at various places along the Brahmaputra to protect a number of important places as well as some of the embanked reaches of the river. Brief descriptions of Dibrugarh protection works are furnished hereafter.

5.1 Dibrugarh Protection Works

5.1.1 Records of Early Erosion in Dibrugarh- As early as 1880-81,some records of erosion by the river Brahmaputra indicate that erosion originated due to the shift of the course of the Dibru river which was flowing in to the Brahmaputra, some 6 km below the town. In the records of the Public Works Department, it reveals that the main channel of river was earlier flowing along the north bank. However, during 1913 flood season due to changes in the river configurations" the main channel took a swing towards south bank and started eroding the river bank at Dibrugarh. This process of erosion continued off and on.

In th.e year 1916, due to renewed activities of the southern channel, the Amolapatty area was under the grip of erosion and some railway properties were lost. Again in 1931 there was a high flood in the river (RL 104.6 m) submerging a portion of the railway line between the railway terminal and the town, however there was no serious erosion that year. During the early part of the flood sei1snn of 1935, erosion took a seriOUS turn in the bazaar area of the town. Serious erosion was also observed in the river front along the Amolapatty railway station, a strip of land 18 m width for a length of 550 m, was lost to the river. The Assam Public Works Department took up some temporary protection works known as "Barua Bamboo Cage" indigeniously designed by Late H.P.Baruah the then Chief Engineer, Assam P. W.D. and was tried as an experimental measures to arrest erosion in the Amolpatty area, by inducting silltation. These works could not produce the desired results. Thereafter, in 1936, the Govt.of Assam referred the matter to the Chief Engineer, Irrigation, West Bengal to suggest a permanent solution for the protection of the town. After his inspection of the affected areas and study of earlier river plans and configuration, he suggested that a stone revetment of adequate design for a length of 2440 m was the only viable solution for the problem of erosion at Dibrugarh. However, the ,work could not be implemented, as suggested, due to financial constraints, Thus, over the decades, due to' the recession of the river bank, the outfall of the Dibru shifted to a point about 4 km upstream of the town.

5.1.2 Erosion after the Earthquake of 1950:- The great earthquake of 1950. which had its epicenter only 50 kms from the International border, caused enormous landslides in the Sub Himalayan hills falling within the watershed of the Brahmaputra. This disastrous episode caused a steep rise in the sediment load of the river resulting in drastic changes in the flow pattern and other hydraulic parameters almost throughout its length in the valley. At Dibrugarh, the river formed a deep embayment near the Bishop's House and started eroding the bank at a very fast rate.

5.1.3 Protective Measures Undertaken to Save the Town: It was decided to evolve measures on a scientific basis and to take up the work, on war footing to meet the challenge of the nature, The Central Water Commission was entrust to draw up plan and programme for implementation within a very brief spell of time . The proposed work was tested in a hydraulic model in the Central Water and Power Research Station(CPWRS), Pune and-a comprehensive plan was drawn up taking into consideration the findings of the model test and other practical considerations. The protection works, thus taken up in 1954, envisaged to arrest erosion for a length of 8 km of the river in front of the town. While the design and programme of these works were drawn up, the findings of the model test conducted at the CWPRS, Pune were fully considered in its formulation. The work, taken in hand in 1954, comprised of Seven numbers of impermeable stone spurs at an interval of 760 m. The Main spur called the 'Kahai' spur was of 120 m length and the last spur was of 30 m length while all other intermediate stone spurs were 60 m long each projecting into the river In addition to the stone spurs, to minimize the return .flow in the vicinity of the impermeable spurs, a series of timber pile spurs were also constructed.

In the most vulnerable reach near the Deputy Commissioner's Court buildings, revetment of proper design, with launching apron was constructed, for a length of 1300 m. In order to prevent flooding due to bank spilling, an earthern embankment was constructed for a length of 9.6 km beginning at the Maijan bridge over D.R. T. lluad alld ellding at Amollapatty, the southern-most ward of the town. Two subsidiary ring bunds were also constructed to protect the George Institution (High school) and the Amolapatty area, falling outside the main dyke.

Due to changed river configuration, a few other anti-erosion schemes on the western as well as eastern sector of the town were executed in the following years to safeguard the entire Dibrugarh town.

5.1.4 Mothola Protection Works- Phase II - Under this work, the bank heads at Ch.7400 & 8300 were strengthened and the bank head at 4800 was constructed out these measures did not yield result.

5.1.5 Mothola Protection Work - Phase III (1975)- In the low water season of 1974 it was recommended by the Board of consultants to execute the following works.

a) Strengthening of bankheads at Ch.4800 and 7400 and converting one of these into a river spur with apron.

b) Construction of 8 No; permeable spurs with stone apron. During the high flood of 1977 these works were badly damaged and a stretch of 300 m was eroded.

5.1.6 Extension of Mothola Protection Work, (1977-78) - In order to arrest erosion at Mothola area, additional 10 Nos. of timber dampeners were constructed with stone apron.

5.1.7 Land Spur at Mothola (1978-79)- The land spur(Ch.7400) of length 300 m and crest level at 1.5 above H.F.L. and apron width of 30 m was constructed. This structure has played a vital role in the protection of the whole area from Mothola downstream covered by the existing Dibrugarh town protection works.

5.1.8 Strengthening of the Dibrugarh Town Protection Works- After completion of the original Dibrugarh town protection works and its subsequent extension both on the upstream and downstream, these required further strengthening from time to time due to rise in the flood level and change in the channel configuration. The strengthening works so executed are in the form of strengthening of the rise & side slopes of land spur at Mothola, strengthening of the Kahai spur, strengthening of the existing stone and pile spurs, providing revetment in between stone spur No. 5 & 6 and the conversion of the permeable spur No. IOA, 12, 13 into semi-permeable spurs.

5.I.9 Embankment System for flood Protection in the Dibrugarh town area - As stated earlier, a marginal embankment 9.6 kms in length was constructed from Maijan to Mohonaghat, along with the original Dibrugarh town protection works, as its integral part to protect the Dibrugarh town area from the Brahmaputra floods. Subsequently, construction of subsidiary marginal embankment for a total length of 2.5 km was taken up during 1964-65 to protect the George Institution and also the Mohonaghat area, lying outside the original embankment. To prevent flooding of the town, through the un-embanked reach upstream of the Maijan bridge, construction of an embankment, 4.7 km in length along the Hiloidhari Road, was taken up in 1977- 78. Thereafter, the construction of another embankment, 9.1 km in length was taken up in the year 1980-81 connecting the land spur at Ch.7400 to the high reach of Oakland T.E. on the upstream.

5.1.10 Future Plan and Programme – At present the land spur at Mothola is playing its role in an effective manner. The southern channel is deflected towardds north, thus the downstream of the Mothola land, *spur* appears to be in a safe zone. Nevertheless, the recurring erosion in Oakland/Nagaghooli area, upstream of the Mothola land spur, is causing concern to the Govt.of Assam. There have been repeated demands from the public of Dibrugarh to take additional protection works in conjunction with the existing town protection works.

Although the protection works executed in the Dibrugarh town area effectively withstanding the river action so far, the erosion has shifted further upstream in the Maijan Nagaghooli area causing extensive erosion during the post years, as stated earlier.

The Brahmaputra is very unstable in this reach, with steep slopes and high sediment load causing frequent changes in the braided channels of the river. Decause of its general tcndcncy to press against the southem balik, tile existing protection works are to be closely observed all throughout, with consult vigilance, particularly' during the flood season. Any changes in the channel configuration in the vicinity of the town area are to be closely watched and recorded regularly in a proper manner for the purpose of taking up corrective measures as may be necessary

6.0 RECOMMENDATION FOR FURTHER STUDIES AND APPROCHES

6.1 Land Erosion

The hill sides are friable and susceptible to erosion. Widespread practice of shifting cultivation (known as jhuming) accentuates the soil erosion. Development works like roads etc., result in washing down of large quantities of sediment.

Earthquakes and landslides bring down large masses of soil interfering with the drainage channels which also accentuates the inundation. Faulty land use, deforestation and high intensity of rainfall also contribute to soil erosion.

Detailed studies of the erosion status of the different catchments will have to be carried out to identify critical areas and prepare schemes for catchment area treatment. All India Land Use Survey Organisation has already carried out surveys for Pagladiya and Subansiri catchments and the critical areas identified. With the aid of remote sensing surveys, areas where extensive landslides have occurred should be identified and action for treating such area should be taken up on priority. Location and capacities of check dams/detention dams would need to be determined,

6.2 Bank Erosion

The tributaries on the north bank come down the steep slopes bringing heavy sediment load. Deposition of this sediment at the outfall causes the tributary mouths to shift resulting in severe bank erosion.

In the braiding formation, all the channels do not carry equal discharge and intensity in one of them increases, thereby increasing the velocity. The increased velocity leads to greater bed and bank scour. Such a change of intensity occurs very frequently and at different places. thus making costly protection works necessary all along the river bank.

From the study of the past data, long term prediction of the future behaviour is considered doubtful because the changes in braiding pattern are erratic and related to the differential deposition pattern. However, prediction on year to year basis can be attempted with a physical model as in case of the Kosi river, Another factor responsible for bank erosion is bend flow along the concave side of bank results in bank failure, Before planning bank protection works, it is necessary to investigate the specifications of Bank failure. Geotechnical Investigations for bank failure have to be carried out

6.3 Bank Failure

In the flood the banks get saturated and during the falling stage of the river, seepage from the banks towards the river increases with the drawdown and the banks composed of sand with low cohesion collapse, depositing large volume of sediment (of bank) into the river which gets washed away. Poor drainage and interspersed layers of sand are additional factor which accentuates bank failure. The reaches which are undergoing active erosion \ are being reassessed from time to time by the State Government due to the changes in the localities of such erosion, The tests so far carried out indicate low cohesion and low internal friction as the main cause for bank instability,

Detailed testing of the engineering properties of soils in reaches which are prone to erosion have to be carried out along with drainage characteristics to enable stable bank slope to be designed. Since the soil from river bed and banks, which is generally used for embankments are fine in character, it is liable for erosion even with low velocity. Bank protection with suitable well defined filter would be necessary.

From the tests carried out on the samples of bank material by the River Research Station(RRS) Guwahati, it is seen that the bank material has very low cohesion and the angle of internal friction is very low and as such the embankments have to be built with flat slopes. At representative locations, more detailed testing should be carried out to confirm such low values and also to carry out proper design of the embankments.

In consultation with forest department, a systematic plantation of suitable fast growing vegetation may betaken up along the banks to help in arresting bank erosion.

Use of brushwood flow retarders has been tried in the past to induce deposition. it has not been successful probably because of inadequate anchoring. The bed undulation of as much as 25 m have been noticed indicating that scour can be quite deep, particularly in channels with high intensity. It may be desirable to consider anchoring the flow retarder below scour level to make them effective. In this connection, it may be pointed that Lacey's regime formula has not been found applicable to Brahmaputra and scour depths may be much in excess of those obtained by using Lacey's formula.

Even in locations where bank failure are occuring, flattening of the natural bank may considerably help in reducing bank erosion thereby helping the stability of the bank.

6.4 Aggradation

As brought out earlier, it is a general belief that considerable aggradation takes place along the Brahmaputra river in most of the reaches particularly in the upper reaches. The earthquakes and landslides in the hills are considered as the main source of the sediment apart from the bank erosion. However detailed analysis of the sixty five cross sections taken along the river, shows that aggradation is limited to very short lengths, that too for short period. Over a long period of 30 years from 1957 to 1989 there is an over all degradation in almost the whole length of the river. The channels keep shifting in position and it cannot be said that anyone channel is getting deeper. The number of flow channels in any section varies from year to year. Shoal formation also does not appear to have any noticeable pattern as the shoals disappear and reappear at different locations even in the same flood event.

As per the studies with the available cross sections, no aggradation has been noticed except in the upper most reaches near Dibrugarh. There have been some anomalies (50 for instance) which need to be investigated. Periodic observations at regular interval at the different cross sections should be made and analysed for future trends. Cross sections at closer intervals would also be necessary. From the old drawings for the embankments, the flood level adopted from time to time may be traced out to examine the increase in flood levels which necessitates raising of embankments. The flood levels of different frequencies .do not show appreciable change. If proper free board is adopted, need for repetitive raising of embankments does not appear justified.

In the period following earthquakes, substantial aggradation in local reaches has been experienced. This is however, temporary till excess sediment gets washed down and original river bed levels are restored, Studies need to be continued to investigate long term bed changes at mouths of the tributaries on the north bank because of the need for tributaries to flow for longer length before joining the new course.

7.0 OTHER POSSIBLE REMEDIES AND STUDIES REQUIRED

7.1 Construction of Reservoirs

It is generally believed that construction of dams would arrest the sediment load of the river and that the braiding of river downstream of the dam would reduce leading to lesser bank erosion, With thc construction of dams, the dominant discharge is likely to flow for a larger percentage of time leading to increased scour of bed and banks. It has also been established that the sediment carrying capacity of the river is higher than the sediment available. Thus arresting of sediment load at the dam may lower the load downstream, which may induce degradation. The fine material of the banks is easily susceptible to erosion and may be a source of supply, increasing the chances of bank erosion. Because of the relatively young age of the river, bed erosion over a period of time has to be expected, When bank protection works are planned, this aspect has to be kept in view.

7.2 Use of Physical and Mathematical Models

Problems related to alluvial rivers can be studied with help of a physical model and/or mathematical models. In the context of their utility in solving the problems of river Brahmaputra, one must know the strengths and weaknesses of these two types of models.

Traditionally the physical movable bed models have been used to solve local problems in rivers such as local protection of banks from erosion using spurs, control of sediment entry into canals, location of bridges, alignment of piers, control of rivers at barrages and bridges, scour downstream of hydraulic structures etc. These studies are conducted using a distorted model using slope exaggeration if necessary. Suitable size of sediment & its relative density are adopted and used so that sediment mobility and transport similarity are approximately attained, Froude number in model & prototype are nearly same, Under these conditions models give qualitative results since models & prototype are not completely similar. In India these types of model studies are often conducted to test whether the proposed measures would be satisfactory.

However, physical models cannot be used where lengths involved are very large and in problems of aggradation upstream of a dam and degradation caused by a dam upstream or by increase in clear water discharge. It also cannot be used when the phenomenon of bed level variation is so slow that physical model cannot be run for a corresponding length of time because of practical constraints,

As regards use of mathematical model for studying morphological changes in the Brahmaputra is to be kept in mind that Brahmaputra is a braided river over a major portion of its length under study. In braided streams there are some permanent islands. Some islands also form and disappear from year to year. Mathematical model for braided condition of streams has not been fully developed and tested. Therefore, one can only use one dimensional model taking into account average bed levels across the width and disregarding islands. This will be permissible only if at any section width occupied by islands is relatively small and constant, otherwise it would be too approximate. Further, to calibrate the model, reliable data on cross sectional details from year to year are needed along with inflow hydrographs from the main river and the tributaries. For this reason, before any use of mathematical model is contemplated, adequate flow and bed level details etc. need to be obtained. Further the accuracy of morphological predictions depends greatly on use of sediment transport relationship which is applicable to the river. Hence more sediment transport data which are reliable are needed on the Brahmaputra before mathematical model studies are undertaken.

7.3 Data requirements and further studies

The Flood Control Department of Assam (FCD) has three stream gauging stations at Bhurbhanda, Bechamara and Pandu. The CWC has one site at Pancharatna.

The observations of vertical distribution of velocity and sediment indicate that there is a variation from the assumption of average concentration at 0.6 D. Periodic observations at all the sites may be taken for further analysis. The Punjab bottle sampler being used may be replaced by more updated equipment for improving reliability.

The observation network including observations of the main tributaries needs to be strengthened to provide more detailed information on the effect of tributaries on the main river.

Cross sections of the river (65 nos) are being taken from time to time. The time intervals range from 14 years (1957 to 1911) to 4 years (1977 to 1981). It would be desirable to take the cross sections say once in 5 years with more uniform time intervals.

7.3.1 Plan Form Changes

At periodic intervals, the satellite imageries and the aerial photographs should be collected and analysed for study of the plan form changes and shoal formation. As the monsoon season data may be affected by cloud cover, data collected soon after the monsoons may be more advantageous.

As Survey of India carries out photography at intervals of about 5 years, the imageries which are available throughout can supplement the photographs for annual study subject to financial constraints.

7.3.2 Bed Forms

Bed form movement may be. studied at two or three sites for different flood levels for obtaining information regarding dimensions and movement of dunes Monitoring at one spot over a period of time and bed undulations as observed in one profile have been included in the present report. This information will be useful for navigation studies.

7.3.3 Geomorphology

Geo-morphological studies have been carried out by GSI only for portions of the main river and three tributaries. It is necessary to carry out these studies for the full length of the river, followed by studies for the tributaries. As this is a continuing work which require sustained effort, feasibility of a core unit in GSI for carrying out the studies may be explored.

7.3.4 Sediment Studies

Bed material surveys have been carried out at about 20 cross sections. Since sediment size is an important parameter in all morphological studies, more detailed information should be collected on the main river as well as of the tributaries.

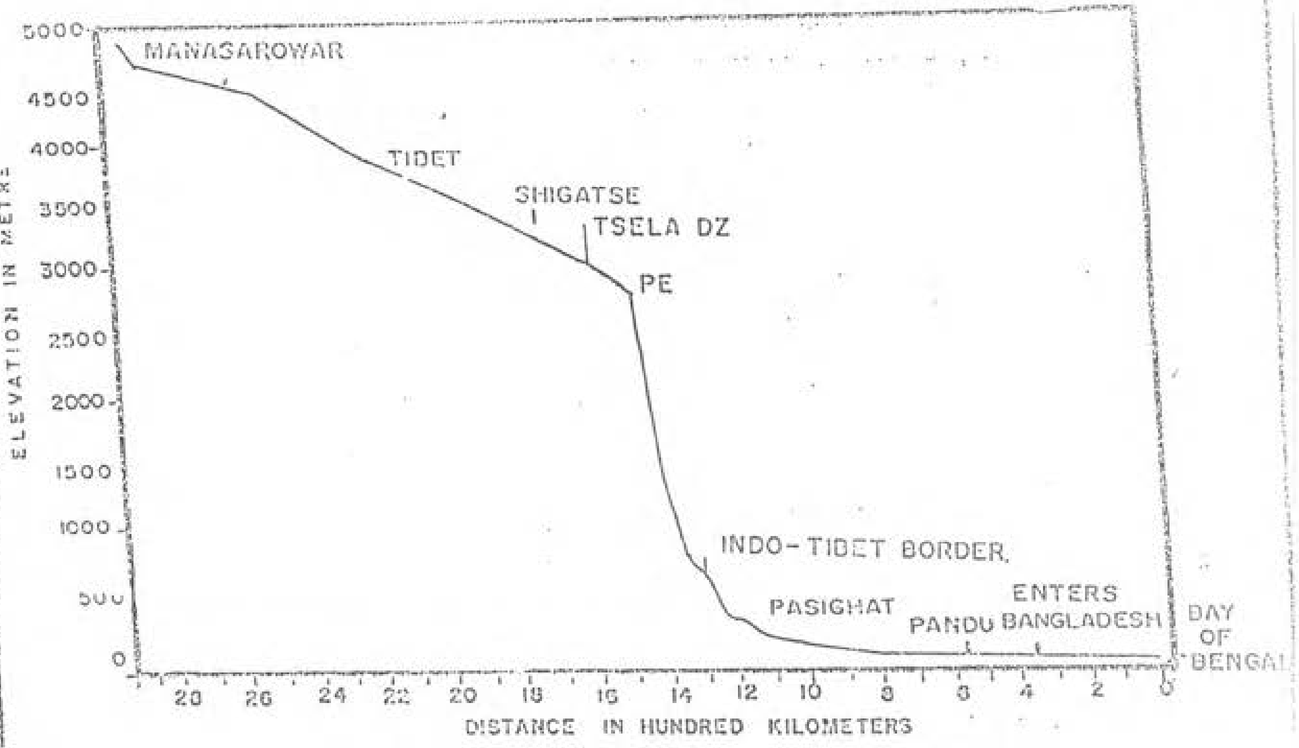
8.0 CONCLUSION:

Had the North east region not been.seismic, the Brahmaputra would have settled to a regime which would have coped with the sediment that annually got into it. The only influencing factors for this sediment would have been heavy precipitation in the region, the steep hill slopes, the fragile nature of the rocks, deforestation and shifting cultivation. The first three are not susceptible of change. The later two can be modified gradually and the effect any consequent change would also be gradual. Therefore manmade causes like uncontrolled deforestation, forest fire, over grazing, improper method of tillage, unwise agricultural practices and other human activities which have accelerated the soil erosion in the river basins needs to be checked urgently.

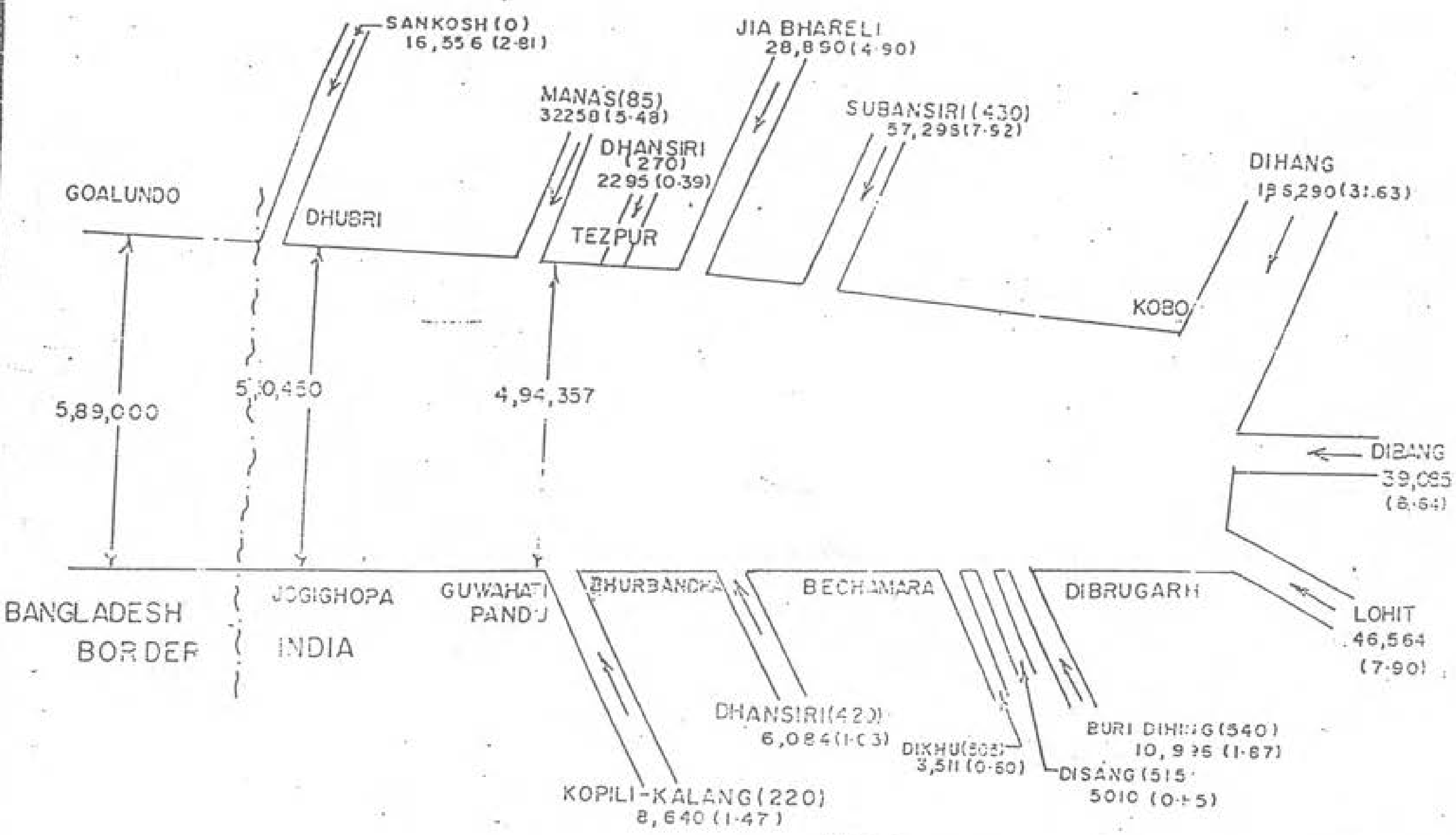
For monitoring in future, the aggradations / degradation tendency of the river all along the concerned reach, cubature studies based on cross sections may be continued. In addition, at all the stream gauging stations, specific discharge gauge plots may be made. Regarding seismic activity, database needs to be built up recording time, intensity and location of epicenter of earthquakes and relationship for excess concentration of sediment on account of seismic activity need to be explored.

In order to keep the riverbed in equilibrium condition and to control the deposition of silt on the bed, various methods of de-silting can be thought off. One of the feasible methods may be Jacketing or constricting the river width with the help of series of spurs on both banks so that the flow velocity increases resulting in movement of bed material. Creation of large reservoirs in upstream is another viable solution which will trap large quantities of silt and reduce siltation of the riverbed downstream. Another very effective method could be the

Watershed Management in the degraded catchments, which will reduce the silt input in the river channel resulting in stabilization of the river course.



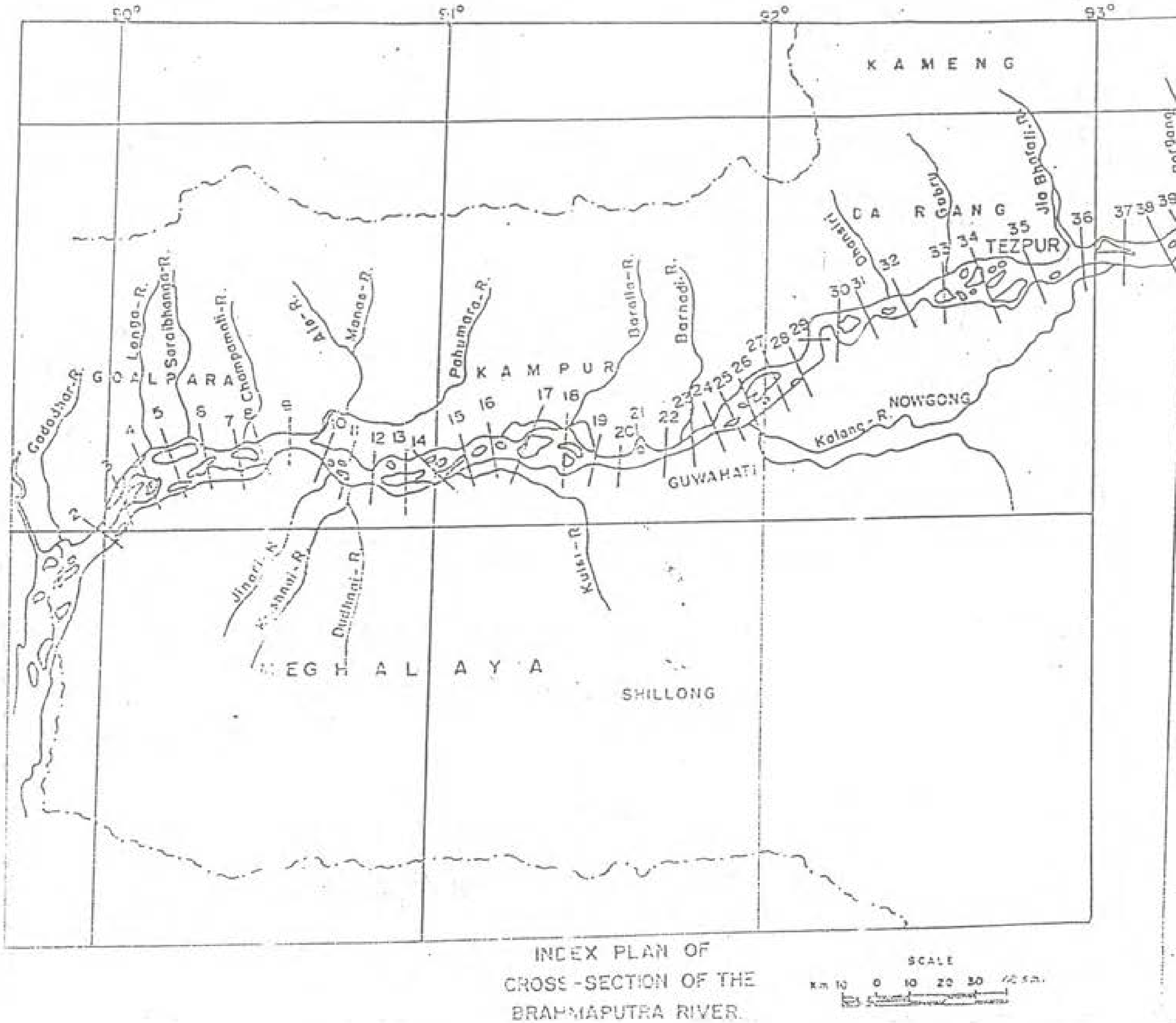
LONGITUDINAL SECTION OF THE BRAHMAPUTRA RIVER



NOTE :-

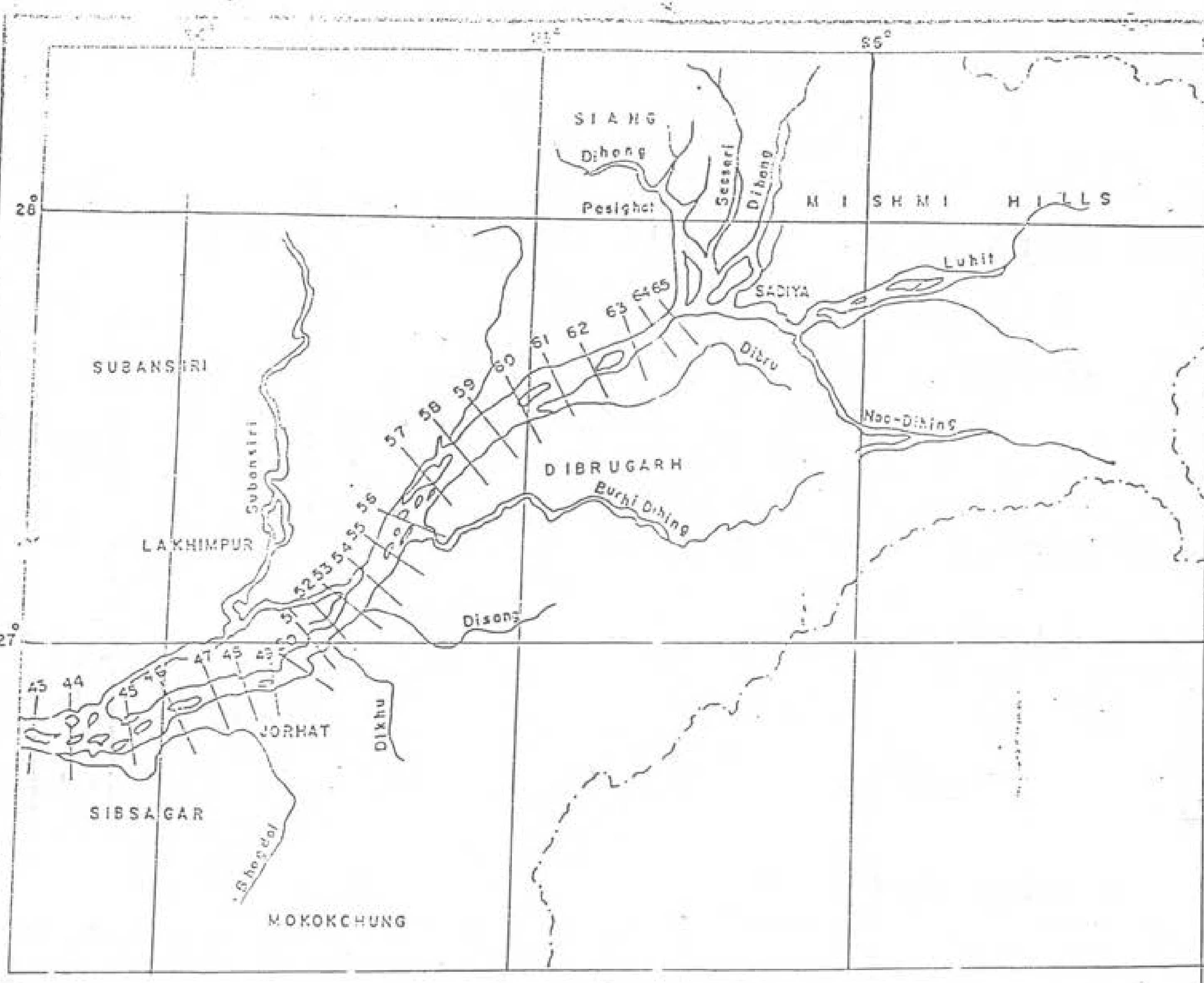
1. FIGURES INDICATE AVERAG ANNUAL RUNOFF IN MILLION CUBIC METERS.
2. FIGURES IN BRACKETS INDICATE CHAINAGE FROM BORDER TOWARDS U/S
3. FIG IN SQ BRACKETS INDICATE PERCENTAGE CONTRIBUTION.

AVERAGE ANNUAL RUNOFF BRAHMAPUTRA



INDEX PLAN OF CROSS-SECTION OF THE BRAHMAPUTRA RIVER.

X-Section No.	Bearing of X-Section	Chainage in Km.
2	299°30'	17·34
3	331°00'	23·05
4	332°00'	30·25
5	337°00'	43·92
6	347°00'	53·01
7	357°00'	63·30
8	332°40'	73·44
9	0°30'	82·62
10	24°40'	92·32
11	16°00'	100·94
12	5°30'	109·63
13	350°00'	119·65
14	310°00'	128·01
15	342°00'	137·70
16	349°00'	146·37
17	22°00'	153·06
18	3°00'	162·23
19	13°30'	173·95
20	3°00'	182·53
21	356°00'	189·21
22	0°00'	197·37
23	350°00'	208·55
24	335°00'	213·13
25	330°00'	218·79
26	335°00'	224·91
27	332°00'	234·60
28	323°30'	241·23
29	270°00'	251·93
30	0°00'	252·15
31	334°00'	272·33
32	334°00'	284·03
33	353°00'	296·83
34	334°00'	30·10
35	337°00'	325·91
36	334°00'	341·21
37	1°30'	20294
38	330°00'	353·13
39	325°00'	371·81
40	334°00'	38803
41.	359°00'	39956
42.	357°00'	393·33
43.	4°30'	412·00



X-Section NO	Bearing (X-Section)	Chainage (IN Km)
44	357°-00'	423·31
45	347°-00'	435·63
46	330°-30'	453·91
47	336°-00'	465·13
48	342°-00'	474·82
49	350°-00'	483·49
50	296°-00'	490·63
51	315°-00'	498·00
52	315°-00'	505·34
53	301°-00'	513·02
54	307°-00'	522·77
55	302°-30'	531·55
56	290°-00'	541·13
57	315°-30'	550·90
58	312°-00'	570·20
59	314°-00'	579·38
60	332°-30'	589·07
61	331°-00'	601·62
62	330°-30'	613·04
63	338°-00'	626·30
64	324°-00'	634·46
65	322°-00'	640·07

INDEX PLAN OF
CROSS-SECTION OF THE
BRAHMAPUTRA RIVER

SCALE
Km 10 0 10 20 30 40 Km

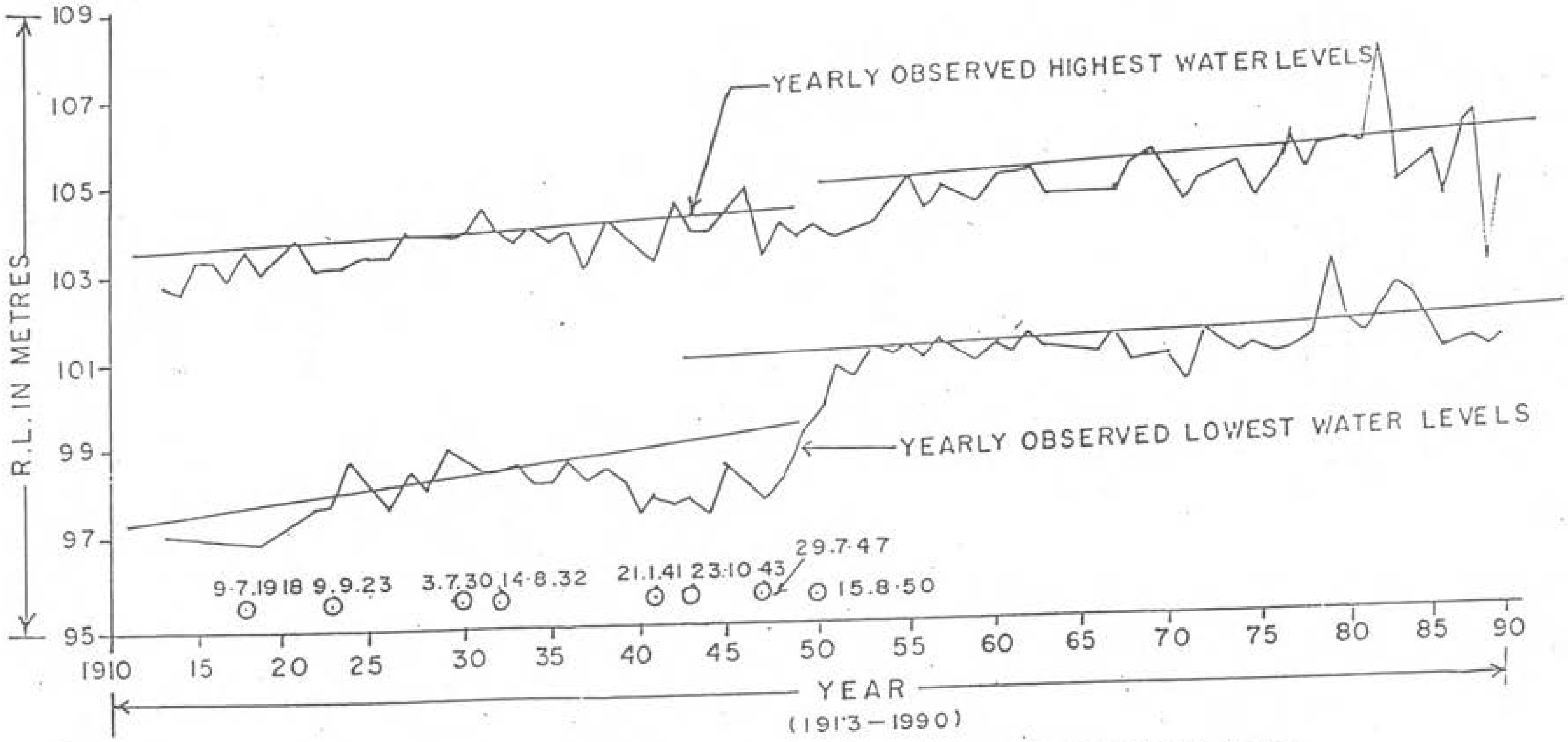


FIG-1 BRAHMAPUTRA WATER LEVELS AT DIBRUGARH
(1913–1990)

SILTATION IN RIVERS - GANGA BASIN

1.0 GANGA BASIN SYSTEM

The river Ganga known as Bhagirathi upto Devaprayag, rises at Gangotri glaciers in district of Uttarkashi (Uttaranchal)at an elevation of 7016 m .After flowing nearly 250 km through hilly terrain, it enters the plains at Rishikesh. From Haridwar, 30 km below Rishikesh, the river flows over the fertile plains of Uttaranchal and Uttar Pradesh. It receives the river Ramganga from left before Allahabad and Yamuna from right at Allahabad. The river flows further 345 km. to Varanasi and in this reach it receives the river Tons from right (South).

The Ganga enters Bihar in the middle region at a distance of 155 km from Varanasi . In this region, it receives on the north, very important tributaries, viz the Ghaghra at Chapra, the Gandak near Patna, the Burhi Gandak opposite Munger, the Kosi in Kursela, and the two arms of Mahananda the right arm joining upstream of Farakka and the left arm joins Ganga (called Padma in Bangladesh) just crossing the Indo-Bangladesh border. From the South , the Ganga is joined by Karamnasa near Chausa at Uttar Pradesh-Bihar border, the Sone near Koelwar, the Punpun at East of Patna, the Kiul- Harohar near Munger, Chandan-Badua near Bhagalpur and Gomani near Farakka. The river Ganga swings around the Rajmahal hill range opposite Manihari ghat (South of Katihar) and starts flowing almost to South. The delta of the Ganga starts from Farakka in West Bengal. The river gets divided into two arms about 40 km below Farakka the left arm called Padma flows eastward into Bangladesh and the right arm called the Bhagirathi flows in southerly direction in West Bengal. The Bhagirathi which flows into West Bengal divides the Murshidabad district into two parts and then forms Eastern boundary of Burdwan district. In this reach it is joined by the river Ajoy. The Bhagirathi receives Jalangi just above Nabadeep town and from there, it is known as Hooghly.

The total length of Ganga from its source to outfall into sea along Bhagirathi and Hooghly in 2525 km of which 1450 km lie in Uttranchal and Uttar Pradesh, 110 km along Uttar Pradesh-Bihar border, 445 km in Bihar and 520 km in West Bengal. The basin has a catchment area of 861 ,400 sq km. which is about 26% of total geographical area of the country. It covers the States of Uttranchal, Uttar Pradesh, Bihar , Jharkhand, West Bengal, Haryana, Himachal Pradesh, Rajasthan, Madhya Pradesh, Chattisgarh and NCT of Delhi. The Ganga basin has been divided into 23 river systems namely Main Ganga Stem, Ramganga, Gomati, Ghaghra, Gandak, Burhi Gandak, Bagmati, Adhwara, Kamla-Balan, Kosi, Mahananda, Yamuna, Tons, Sone , Punpun, Kiul-Harohar, Badua-Chandan, Mayurakshi, Ajoy, Damodar, Rupnarayan-Haldi Rasulpur, . Jalangi and Tidal rivers. The index map of Ganga basin is shown in Plate-I.

2.0 SILTATION PROBLEM IN GANGA BASIN

Longitudinal bed slopes of the river Ganga and its tributaries are steep in upper reaches, become flatter in middle reaches and turn level in estuaries. The upper courses are noted predominantly for deep erosion i.e., bed retrogression. The scoured material is carried downstream by the flow and the middle courses from Eastern Uttar Pradesh to Farakka (for the Ganga) have evidence of both deep erosion and aggradation. The lower reaches below Farakka where the bed slope and velocities are small are known mostly for accumulation process i.e. sedimentation of most of area manifested in curving and extending of the river bed in plan.

Normally transverse circulation develops in the natural streams/ rivers, which inevitably becomes curvilinear in plan with uneven distribution of depth over the river bed section and along longitudinal profile. Laterial erosion occurs as the result of transverse circulation and centrifugal forces acting at curvilinear sections of the river causing its bed to perpetually find its way along the sediment deposit in the river valley leading to degradation of bank slopes, shoal formation etc. The evidence of erosion is particularly conspicuous in river stretch where flow velocity changes, at bends, branchings, confluence of tributaries, etc.

Himalayan rivers which flow in this region carry high discharges and large quantities of sediment from the friable slopes of mountains and tend to deposit the same in the lower flatter areas before their confluence with river Ganga causing reduction in channel capacities resulting in extensive over bank spills and consequent inundation. Changing of river course and braiding channel is another prevalent phenomenon in the region. The Ganga, itself while maintaining high flood stages affects the drainage from its tributaries causing acute bank erosion problems. Silt load in the stream depends on (i) nature of soil in the catchment (ii) topography of the catchment area and (iii) intensity of rainfall. Ruthless exploitation/denudation of forests, over grazing and improper management of agricultural lands over many years has exposed the undulated surface to the beating action of rain. Most of the rain that falls on such areas, rushes down the sloping lands as runoff water eroding the top soil and gradually rendering it incapable to sustrain plant life. Thus the eroded soil finally deposits as silt in the river bed reducing its carrying capacity.

3.0 SILT OBSERVATION SITES IN GANGA BASIN RIVERS SYSTEM

Ganga basin rivers system is extensively covered by the silt observation sites. Silts observation are being carried out by field offices of Central Water Commission, Annual silt data book is also brought out by C.W.C. List of the important silt observation sites are given in the table below:

LIST OF THE IMPORTANT SILT OBSERVATION SITES IN GANGA BASIN RIVERS

Sl no.	River	Site
1	2	3
1	Main Ganga	
i.		Garhmukteswar
ii.		Kachla Bridge
iii.		Fatehgarh
iv.		Ankinghat
v.		Kanpur
vi.		Bhitaura
vii.		Shahjadpur
viii.		Allahabad
ix.		Varanasi
x.		Mirzapur
xi.		Buxar
xii.		Gandhighat
xiii.		Hathidah
xiv.		Farakka
2.	Ramganga	
i.		Rampur
ii.		Bareily
iii.		Debri
iv.		Hussepur
3.	Sarda	
i.		Paliakalan
4.	Gomati	
i.		Lucknow
ii.		Maighat
5.	Ghaghra	
i.		B.K.Ghat/Katarniaghat
ii.		Elgin Bridge
iii.		Ayodhya
iv.		Turtipar

1	2	3
6.	Rapti	
i.		Balram;ur
ii.		Regauli
iii.		Birdghat
7	Sone	
i.		Phaphund
ii.		Kulda Bridge
iii.		Jhukoo
iv.		Chopan
v.		Kota
vi.		Md. Ganj
vii.		Jalpa
viii.		Koelwar
8	Gandak	
i.		Tribeni
ii.		Dumariaghat
iii.		Lalganj
9.	Burhi Gandak	
i.		Sikandarpur
ii.		Rossera
10	Bagmati	
i.		Dheng Bridge
ii.		Hayaghat
11	Adhwara Group	
i.		Kamtaul
ii.		Ekmighat
iii.		Saulighat
12	Kamla-Balan	
i.		Jainagar
ii.		Jhanjharpur
13	Kosi	
i.		Baltara
ii.		Banmankhi
14	Mahananda	
i.		English Bazar
ii.		Siliguri
iii.		Sonepur Hat
iv.		Taibpur
v.		Dhengra Ghat
vi.		Jana Railway Bridge
15	Bhagirathi	
i.		Farakka Feeder Canal
ii.		Berhampur
iii.		Katwa
iv.		Kalna (Ebb)
v.		Kalna (Flow)

16	Jalangi	
i.		Chapra
ii.		Purbasthali
17	Ajoy	
i.		Jamtara
ii.		Nutanhat
18	Damodar	
i.		Chanpadhengs
ii.		Jamalpur
iii.		Harinkhola
19	Yamuna	
i.		Pratappur
ii.		Auriya
iii.		Etawah
iv.		Agra
v.		Mathura
vi.		Mohna
vii.		Delhi
viii.		Mawi
20	Chambal	
i.		Udi
ii.		Dholpur
iii.		Tal

4.0 Silt Load in Ganga Basin Rivers

The sediment data available for the rivers are essentially for suspended load which include sediment concentration in million ton per annum. The size grades are coarse (>0.2 mm), medium (0.2-0.075mm) and fine (< 0.075 mm). The coarse and medium fractions are interpreted as 'temporary suspended bed load' where as the fine fraction is the 'wash load'. The information on silt load and their distribution, presented in subsequent paragraphs are based on the 'Sediment Year Book' for various sites in Ganga basin brought out by Central Water Commission.

4.1 The Ganga River (Main Stem)

The main Ganga rises in the Gangotri glacier in the Himalayas at an elevation of about 7010 m above M.S.L. in Uttarkashi district of Uttranchal and after flowing in Uttranchal, Uttar Pradesh, Bihar and West Bengal, it outfalls into Bay of Bengal. Two rivers namely the Bhagirathi and the Alaknanda join at Deoprayag and after the confluence, the combined river is known as the Ganga. The main Ganga stem extends between lat 22 17' 30" N to 32 15'N and Long. 77 30'E to 80 30'E. The main Ganga drains an area of 1,10,710 sq.km, which also include Karamnasa, Daya and Bagmati-Pagla river system, as these tributaries directly join the main Ganga river and they do not have any significant flood problem of their own.

The Central Water Commission has 23 silt observation sites on the main Ganga stem namely Deoprayag (ii) Rishikesh (iii) Rudraprayag (iv) Garhmukteshwar (v) Kachla bridge (vi) Fatehgarh (vii) Ankinghat (viii) Kanpur (ix) Bhitaura (x) Shajjadpur (xi)Allahabad (xii)Mirzapur (xiii) Varanasi (xiv) Buxar (xv) Patna (xvi) Hathidah (xvii) Azmabad (xviii) Farakka (xix) Rampur (xx) Berhampore (xxi)Purabasthali (xxii) Kalna(Ebb) (xiii)Kalna (Flow).

It has been observed that the main Ganga carries very heavy amount of silt during monsoon months at all silt sites. Bhagirathi river also carries a heavy load of silt during monsoon months at all sites. The average annual silt load for Azamabad and Farakka sites are 213 and 354 million ton respectively.

From the perusal of silt data it is seen that at Allahabd site on the Ganga river during the monsoon period average fine silt accounts for 76.37% of the total silt while 16.74% accounts for medium & remaining 6.89 % is the fine silt. Moreover, during the monsoon months the silt change is not uniform. The months of August & September account for more silt than the other monsoon months.

At Mirzapur site on the Ganga river, during monsoon months on an average fine silt accounts for 78.83% of the total silt load while 14.85% accounts for medium and the remaining 6.32% is the coarse silt. As in the case, the silt load is not uniform during the monsoon and the months of August and September account for more silt load than the other monsoon months. Moreover , if the average silt data in monsoon period at sites Allahabad and Mirzapur are compared, it is found that in monsoon months the total average sediment loads in Allahabad are more than that at Mirzapur site which means that there is deposition of sediment between these sites.

At Varanasi site on the main Ganga river, during monsoon months on the average fine silt accounts for 84.38% of the total silt load whereas the medium and coarse accounts for 12.62% and 3% of the total silt load respectively. In this case also, the silt load is not uniform during the monsoon months and the months of August and September account for more silt than the other monsoon months. If the monthly average silt data for monsoon period at Allahabad, Mirzapur & Varanasi are compared, it is found that the percentages of coarse and medium silts are gradually decreasing whereas the percentage of fine silt is increasing which is quite normal to expectation that the silt becomes finer as we move downwards from Allahabad to Varanasi.

If the monthly average silt data in monsoon floods for the main Ganga river at Buxar, Patna, Hathidah and Azmabad sites are compared, it is found that on the average total sediment load during the monsoon months is gradually .increasing as we go downwards from Buxar to Azmabad . The reason behind this increase can be attributed to the huge silt carried by the lateral tributaries joining main Ganga river between Buxar and Azmabad. The silts of Gandak, Adhwara group of rivers, the Kosi and others have been remarkably high and this increase is due to silt carried by lateral rivers. At Buxar site on the Ganga river, during the monsoon months on the average fine, medium and coarse silts account for 91.33%, 7.32% and 1.35% respectively of the total silt load and the major amount of silt load is being carried away during the monsoon months of August & September.

At Patna site on the Ganga river, during the monsoon months on an average fine, medium and coarse silt account for 83.58%, 12.98% and 3.44% respectively of total silt load and major amount of total silt load are being carried during the monsoon months August & September. At Hathidah site on the Ganga river during the monsoon months on the average fine, medium & coarse silt account for 67.91%, 23.45% and 8.64% respectively of the total silt load and the major amount of silt is being carried the monsoon months August & Sept.

At Azmabad site on the Ganga river, during the monsoon months on the average fine, medium & coarse silt account for 84.96%, 9.22% and 5.82% respectively of the total silt load and the major amount of the total silt is being carried away during the monsoon months August & September. At Farakka site on the Ganga river, during the monsoon months the fine, medium and the coarse silts account for 94.08%, 3.82% and 2.10% respectively of the total silt load and major account of total silt load is being carried during the monsoon months August & September. At Berhampore site on the Bhagirathi river, during the monsoon months the fine, the medium and the coarse silts accounts for 85.51 %, 10.73% and 3.76 % respectively of the total silt load and major amount of that silt load is being carried during the monsoon months August & September.

4.2 Ramganga River

The Ramganga river is the first major tributary to main Ganga on its left bank flowing through the States of Uttaranchal and Uttar Pradesh . It rises in the lower Himalayas at an altitude of 3440 m above MSL at North latitude 45 5' and East longitude 79 16' near village Lobha in the Chamoli district in Uttranchal . It outfalls into main Ganga after traversing in total length of about 596 km. Its catchment area 32493 sqkm lies between longitude 78 15'E to 80 5'E and latitude 27 5' to 36 6'N.

It can be inferred that Ramganga river carries excessive silt at Bareilly site during monsoon period . It has shown upward trend in average annual silt content from last decade. The total average annual silt load for sites Bareilly and Dabri on river Ramgangas are 6.9 and 3.98 million ton respectively. At Bareilly site on river Ramganga average, fine, medium and coarse silt size percentage are 96.24%, 1.99% and 1.77% respectively. From the perusal of silt data it is seen that even during monsoon months, the silt charge is not uniform. The months of July and August account for more than the other monsoon months.

4.3 The Yamuna River

The Yamuna river is the biggest right bank tributary of the Ganga. It originates from the Yamnotri glacier in the Tehri Garhwal district of Uttranchal and flows through Uttranchal, Uttar Pradesh, Himachal pradesh, Haryana, Delhi and again Uttar Pradesh before it outfalls into the Ganga river on the right bank at Allahabad. The total catchment area of this river system is 366223 sq km. Sediment load is observed at 23 hydrological sites of Yamuna basin maintained by CWC. The analysis shows that Pratappur on Yamuna has on an average yearly Silt flow of 61.45 million ton while second is Auraiya (28.67 million ton). On Chambal River Site Dholpur has average annual silt flow of 3582 million ton. Other River system of Chambal basin like Betwa at Sahjina, Kalisindh at Barod, Ken at Banda, Parwan at Aklera have also considerable amount of silt load. At Pratappur site average fine, medium and coarse silt size percentage are 98.47,3.15 and 1.38 resepctively. Grain size analysis shows that Mawi on Yamuna has maximum average percentage of coarse and medium silt load while Pratappur which is thelast silt measuring site of Yamuna before its confluence with Ganga has maximum percentage of fine silt flow and minimum percentage or coarse and medium silt flow.

In recent years emphasis has been laid on soil conservation measures in the river valley. The silt observation help assessing the effect of these measures. Some soil conservation measures have been taken in Himachal pradesh and western Uttar Pradesh. There appears to be a need for studying the silt load variation with time in order to assess efficacy of soil conservation measures.

4.4 The Gomati River

The Gomati catchment is bounded between lat 25 25' N to 28 45' N and Long. of 80 10' E to 83 10'E. The river flowing through State of Uttar Pradesh has a catchment area of 30435 sq km. Average annual sediment load at site Hanuman Setu in 0.35 million. From the silt analysis, it is seen that the fine silt accounts for 87.8% of the total silt load, 8.8 % is accounted by the medium silt and 3.4 % accounted for the coarse silt. The sediment load due to flat slope of Gomati and its major tributaries like Sai, Sarayan, Kalyani and Kathna which originate in plains, get deposited in the bed which causes river course to meander

4.5 The Sone River

The Sone river is one of major right bank tributaries of the river Ganga. It originates from Amarkantak high lands in the Maikala range of hills in the Bilaspur district of Chattisgarh at an elevation of 640 m at lat. 20 44' N and long . 82 04'E . The river outfalls into Ganga about 16 kms upstream of Danapur. The river covering the States of Chattisgarh , Madhya Pradesh, Uttar Pradesh, Jharkhand and Bihar has a catchment area of 70055 sq km.

Central Water Commission is maintaining seven silt observation sites in the Sone River system where silt observation are taken regularly. The sites are Chopan, Kuldah bridge, Kota, Jhukoo, Japla, Mohammadganj and Koelwar. The averge annual silt load at Chopan and Koelwar are 20.00 and 46.52 million ton respectively.

4.6 The Ghaghra River

The Ghaghra river originates from Himalayan glaciers in Tibet at an elevation of 5500 m and out falls into the Ganga near Chapra town in Bihar. The river flowing through States of Uttar Pradesh and Bihar has a total catchment area of 127350 sq.km out of which 57647 sqkm lies in India. The average annual silt load at Elgin Bridge and Turtipar sites on river Ghaghra are 40.1 and 110 million ton respectively.

The fine silt size accounts for 70% of the total silt load while 25% is accounted by the medium and 5% by the coarse silt at Turtipar site. Similarly for Elgin bridge and Katarniaghat sites, the fine silt accounts for 69% and 61%, medium 20.5% and 26% and coarse 10.5% and 13% respectively.

4.7 The Gandak River

The Gandak river rises in Himalaya at an altitude of 7620m North of Dhaulagiri in Tibet near Nepal. The river flowing through the State of Uttar Pradesh and Bihar has a total catchment area of 46300 sq km out of which 7620 sq km lie in India. The river exhibits the serious meandering tendency and in the past it has moved westwards by about 4 to 5 kilometres during the last 50 years. This trend of westerly movement appears to be still continuing in the shape of continual attack on the western embankments. Signs of bed erosion and silt deposition are also noticeable. One of the main reasons for this extra ordinary shift in its course has been attributed to the excessive silt charge. The causes of excess silt movement are mainly because of deforestation resorted to for cultivation on the slopes and felling of forest trees for timber or fire wood. Besides, frequent land slides during monsoon also contribute considerably to the silt charge.

The seriousness of silt problem in the basin deserves urgent attention towards taking suitable measures to minimize the silt load which is mostly generated in the hilly catchment lying in Nepal. Probably this is very difficult as the area is not accessible for transportation of the materials required for soil conservation and other watershed management. Nevertheless, serious efforts should be made so that effective solution to the silt problem in the Gandak river system originating in the upper reaches could be found out. This will go a long way in relieving some of the associated problems in the lower reaches lying in the State of Bihar.

The Central Water Commission has silt observation sites on this river at three places namely, Lalganj, Dumariaghat and Tribeni. Average annual silt load at these sites are 46, 41 and 95 million ton respectively. At the Triveni site fine silt accounts for 82.13% of the total silt load while 13.95 % accounts for medium and the remaining 3.92 % is coarse silt. At Dumariaghat the fine, medium and coarse silt are in the percentage of 64.94% , 26.83 % and 8.23% respectively. The corresponding figures for Lalganj site are 75.50% 17.40% and 7.10% respectively. At Tribeni site that on an average, 97.5% of the silt load comes down the river during the monsoon months i.e. June to Oct. and the balance 2.5% is distributed in the remaining 7 months of the year. At Dumariaghat, on an average 95% of the silt load comes down during the monsoon months and remaining 5% is distributed in the balance months of the year. At Lalganj, the river carries 95.45% of the silt load during the monsoon months with the remaining 4.55 % being carried during the balance months of the year. Even during the monsoon months, the silt charge is not uniform. The months of July and August account for more than the other monsoon months. Value of silt content is the minimum during the month of February and March.

4.8 The Burhi Gandak River

The Burhi Gandak river is a left bank tributary of river Ganga which extends between lat. 25 25'N to 27 30'N and long. 84 0' and 86 30'E. In the North the Someshwar ridge of hills bound it. While the river Ganga forms its southern boundary eastern and western boundary are ridge lines separating from Bagmati & Gandak catchment. It outfalls into Ganga at Khagaria. The river flowing through the State of Bihar has total catchment area of 12500 sq.km out of which 10150 sq.km. lies in India. The annual average sediment load of Sikandarpur and Rosera sites are 9.13 million tons and 13.12 million tons of which 98% and99% sediment load observed during the monsoon period respectively. The average sediment during the decade of sixty is minimum and had gradually increased over the years and is maximum during the decade of eighties. The average monsoon sediment is 97% to 99% of the annual sediment.

The analysis of sediment data of Sikandarpur site indicates that out of annual average suspended load of 9.13 million tone. 4.9 % is coarse, 17.9% is medium and 77.2 % is fine. Similarly Rosera site for the period 1978-89 indicates that out of annual average suspended sediment load of 13.12 million ton, 2.8 % in coarse, 9.4% is medium and 87.8% is fine. These analysis show that the sediment load at Rosera is more than the sediment load at Sikandarpur and the percent fraction of medium sediment at Rosera is 9.4 % whereas for Sikandarpur it is 17.9%. However, at both the sites the suspended sediment mainly consists of fine sediment the contents of which vary from 65% to 91% in case of Sikandarpur and 77% to 94% in case of Rosera site.

Technical Expert Committee on Drainage and Waterways of Railway and Road bridges had also collected some silt data at three different sites of the Burhi Gandak namely Chanpatia, Sikandarpur and Goraul site (Near Dholi). They have analysed the collected data. It has been observed by them that the silt carried by the river in the upper reaches consists of almost equal percentage of medium and fine silt. But as the river flows in the lower reaches the percentage of fine silt content increases and it is as much as 84% of the total silt content at Goraul site (Near Dholi).

4.9 The Bagmati River

The Bagmati river originates at about 16 km North-East of Kathmandu at an elevation of 1500 m. in the Shivpuri ranges of hills in Nepal. The river flowing through State of Bihar has a total catchment area of 8440 sq. km out of which 3720 sq km lie in India. Its important tributaries are Labakeya on the right bank and Lakhandale and the Darbhanga Bagmati on the left bank.

In the Bagmati river system silt data are observed at Dheng Bridge and Hayaghat sites by CWC, at Noonthore by HMG Nepal and at Maksudpur by the State Govt. of Bihar. The Nature of silt varies from fine loam to coarse pebbles. The average annual silt load passing through Dheng Bridge site is 10.41 million ton and Hayaghat site is 7.21 million ton.

The analysis of sediment data of Dheng Bridge site indicates that out of annual average suspended sediment load of 10.41 million ton, 7.6 % is coarse, 26.2% is medium and 66.2 % is fine. Again, the analysis of sediment data of Hayaghat indicates that out of annual average suspended sediment load of 7.21 million ton, 5% is coarse, 19.2% is medium and 75.8% is fine. These analysis show that most of the coarse and medium suspended sediment load gets deposited in the middle reaches of the river system and substantial quantities of finer materials are carried down to the lower most reaches. The deposition of the coarse and medium sediment load in the middle reach has been due to reduction in velocity of flow of the river due to flattening of the river slope.

4.10 The Kamla – Balan River

The Kamla –Balan river originates from lower foot hills of the Himalayas. The catchment area extends between lat. 25 43' N to 27 15' N and long. 85 50'E. It debouches into plains at Chisapani in Nepal, 48 km. upstream of Indo-Nepal Boarder and flowing through plains outfalls into the Kareh in Bihar. Out of total catchment area of 5563 sqkm, 1963 sq.km lies in Nepal and remaining 3600 sq km in India (State of Bihar).

Silt data are at present observed by the CWC at two sites viz. at Jainagar since 1980 during monsoon period and at Jhanjharpur where the observation is carried out through out the year since 1961.

The analysis of sediment data for seasonal sediment site Jainagar indicates that average monsoon (June to Oct.) annual sediment load of the river is 9.68 million ton out of which 30% is coarse, 33% medium and 37% fine. At Jhanjharpur site average annual sediment load of the river is 5.68 million ton out of which only 5% is coarse, 23 % medium and rest 72% fine. This shows that most of the coarse and medium sediment gets deposited in the middle reaches of this river and substantial quantities of finer materials are carried down to the lower most reaches. The deposition of the coarse and medium sediment in the middle reach has been due to reduction in velocity of flow due to flattening of the river slope. This excessive sediment has put the river regime in disarray and created problems like rising of river bed and the flood level, reduction in channel capacity, drainage congestion, meandering of river course, bank erosion etc.

A small lower most portion of the catchment receives sediment from the spills of river Kamla as well as from the river Kareh. Sediment on river Kareh is observed at Hayaghat site by the CWC. In comparison to Kamla, the river Kareh mostly brings down the fine sediment in this zone as all its coarse and medium sediment gets deposited above Hayaghat site. A comparison of fraction of coarse, medium and fine sediment at Hayaghat and Jhanjharpur indicates that fraction of fine sediment at Hayaghat ranges over 90% of the total sediment load except in the months of May, June and July when it is around 72-73 percent. On the whole, at this site, the quantum of fine, medium and coarse sediment is in the preportion of 81.8% , 14. 5% and 3.7% respectively. The monsoon silt load constitute about 70% & 80% of total annual sediment load at Hayaghat and Jhanjharpur respectively. The maximum sediment is in the month of August, September and October. At Jhanjharpur, there is little fluctuation in the proportion of the three fractions of the sediment in any month. The fine sediment is almost account for 75% only.

4.11 The Adhwara River

The Adhwara river system extend between latitude 26 N to 26 50' N and longitude 85 45' E to 80 E. The total catchment of the river system is 4965 sq.km out of which 3600 sq.km. lie in India (State of Bihar)

Khiroi and Darbhanga- Bagmati are the two principal rivers of Adhwara basin. They originate from the foot hills of the Himalayas and donot carry a hevy load of sediment. They do not exhibit any serious meandering tendency and the river cross sections do not indicate any noticeable signs of bed erosion or silt deposition on a large scale. This is borne out from the comparative study of the silt loads carried by various rivers.

Average annual silt load Darbhanga Bagmati at Saulighat and Ekmighat are 0.7 million ton and 0.52 million ton . At Saulighat the fine silt accounts for 87.73% of the total silt load while 10.27 % is accounted by the medium and 2% by the coarse silt. At Ekmighat the fine, medium and coarse silt are in the proportion of 84.35%, 13.15% and 2.5% respectively . The monthwise analysis of silt data indicates that the sediment load transported during the monsoon months is about 58% of the annual load at Saulighat and 76% at Ekmighat. The maximum sediment load is generally in the month of June.

4.12 The Kosi River

The Kosi river system, one of the major left bank tributaries of the Ganga river, originates at an altitude of 7000 m in Himalayas. It lies between long. 85 E and 89 E and Lat. 25 20' N and 29 N . In the North it is bounded by the ridge separating it from the Brahmaputra river, the river Ganga forms its southern boundary. The Eastern and Western boundaries are the ridge lines separating it from Mahananda and the Gandak/ the Burhi Gandak catchment respectively. The river flowing through the State of Bihar has a total catchment area of 74600 sq.km out of which 11170 sq km. lie in India.

The river is notorious for its capricious nature. It carries with it an enormous load of sand which deposits it in the main drainage channel and the Ganga river. In the process of building up an island delta, it has shifted over 112.6 km from East to West during the period from 1736 to 1964. One of the burning problems in Kosi basin is the excessive sediment load brought down by the river. Most of the Experts are of the view that solution to the problems in the Kosi basin lies in the solution of the silt problem,

The average annual silt load carried by the river is about 133 million ton as observed at Barahkshetra site and 94.30 million ton at Baltara.. It has been found by actual observation that about 95% of the silt load comes down the river during the monsoon. Another important aspect is that out of three tributaries i.e. the Sun, the Arun and the Tamur, though the catchment area of the Tamur is only 10% of the total, it brings as much as 23.9% of the total silt. The coarse silt in the Tamur is over 25% of the entire coarse silt in the river Kosi. The average annual silt load in Sapt Kosi as observed at Barhkshetra is about 133 million ton, with a composition of about 16%, 28% and 56% of coarse, medium and fine sediment respectively. It has been further observed that there is appreciable increases in silt load between Barahkshetra and Chatra. The contriobution to the total sediment load in the river from this region is as much as about 25% during flood times. The contribution to the coarse fraction of the sediment load is still higher, being about 39%. This increase is evidently from the Kholas that run into the river in the reach from Barahkshetra to Chatra from either sides.

The higher silt load from the Tamur basin is ascribed to the unstable geological nature of that area. A wide area on either side of the Sapt-Kosi between Tribeni and Chatra is geologically known as thrust zone wherein due to folding and faulting accompanying sustained building activities, the older rock strata underneath have slided over and covered the much younger rock formations above. This reversal of the older rocks riding over the younger ones has brought to bear excessive stresses which has resulted inconsiderable shattering of the rocks over the area and on its margins. In additon, the frequent seismic disturbances, particularly the intense earthquake of 1934, have further accentuated the process of loosening up and disintegration of the already shattered rocks in this region. This shattered zone extends over the area through which the Sun and the Tamur Kosi flow and constitutes a major contributory factor for the excessive sediment and bed loads carried down by the two rivers. Catchment area contribution to Sapt Kosi below Tribeni by the tributaries, the Sun, the Arun and the Tamur are 32% , 58% and 10% respectively whereas their silt load contribution are about 47.5%, 39% and 24.5% respectively.

The bed load reconnaissance surveys on the river was also conducted by the project authority at various locations from Chatra upto 160 km in the downstream. It was found that the bed load consisting of boulder, pebbles and shingles generally get deposited between Chatra and Hanumannagar. The coarse pebbles and shingles rarely come below Belka. The lighter shingles get deposited upto Hanumannagar especially along the left flank of the river. On the right side the bed material is finer and even clayey at places on account of the bank erosions at and below Relka . Coarse and very coarse sediments are deposited upto about 16 km. downstream of Hanumannagar. Beyond Kamrail, which is about 61 km downstream of Hanumannagar, the coarse materials practically disappear. The bed materials here are mainly composed of medium and fine grades of sand and clay.

The Belka nose, where the slope flattens from 95 cm to 61 cm per km is obviously the place where most of the bed load is dropped. The consequent aggradation of the river bed then results in a braided pattern for the river upto nearly Hanumannagar. Below Hanumannagar, there is a further flattening of the slope to about 38 cm per km. which continues upto Sikrahata and Bhantiahi. Beyond, there is a further flattening of slope to about 19cm per km. It is in this reach where the slope changes and most of the coarse sediment gets deposited. Only medium and finer materials are found below Kharhara about 64 kms. downstream of hanumannagar. Below Jamalpur which is about 86 km. downstream of Hanumannagar, the medium grade materials also practically disappear.

4.13 The Mahananda River

The Mahananda, being a Himalayan river flowing through States of West Bengal and Bihar with a total catchment area of 23700 sq.km out of which 17440 sq km lie in India, is not stable. The process of erosion in the steep hilly catchment, transportation of sediment in the river and its subsequent progressive deposition lower down in the river with flatter slopes is a continuing one. The river emerging from mountains into the plains carries heavy silt load and a part of it is finally transported to the Ganga after the deposition of silt either in the bed or in the flood plains while spilling the banks. In the upper reaches in the plains the Mahananda river and its tributaries have got steeper slopes as compared to the lower reaches, thus, the carrying capacity for the silt load in the upper reaches in the plains is comparatively more than in the lower reaches. The river bed, just after it debouches into the plains, consists of silt and sand, whereas further down in the flatter plains the alluvial channels mostly consist of coarse and medium silt.

The silt observation stations on Mahananda river are located at Siliguri, Sonepurhat and English Bazar in West Bengal and Taibpur, Dhengraghat and Jhaua Railway Bridge in Bihar. There are only two silt observation sites namely, Garbandenga on Eastern Kankai and Haribitha or Singhimari on Western Kankai in Bihar.

The annual minimum, average and maximum silt load for Taibpur site 2.59 million ton (1968), 3.00 million ton and 5.20 million ton (1969). Mahananda river at Taibpur carried the average percentage of coarse, medium and fine sediment load in the order of 29.72, 47.27 and 23.01.

4.14 The Damodar River

The Damodar river originates from the Palamau hills of Jharkhand. It bifurcates into two channels at Beguahana. The main flow passes through Mundeswari Channel and discharge into Rupnarayan. The other is Amta Channel, which carries discharge during high flood and outfalls into Hooghly. The total catchment area is 31220 sq km.

In 1959 the committee for Augmentation of water resources of D.V.C has come to the conclusion that the actual annual silt deposition may be 80% higher that estimated by S/Shrri Iyengar & Murthy. The corresponding estimates for each of the four reservoirs are given below:-

Estimated Annual silt deposit and life of reservoirs as A.W.,R.Committee

Sl no	Name of Reservoir	Estimated Annual silt load Ham	Estimated life of the reservoirs years
1	2	3	5
1.	Tilaiya	65	115
2	Konar	36	168
3.	Maithon	110	189
4.	Panchet	313	57

Survey on sedimentation were carried out again in 1963, 1965, 1971 in case of Maithan reservoir, in 1962, 1964, 1966, & 1974 in case of Panchet reservoir, and in 1967 for Tilaiya reservoir. The following table gives comparative data on sediment yield in case of Maithan and Panchet reservoir.

Sediment rate in Maithan and Panchet Reservoirs and loss of storage capacity.

	Maithan	Panchet
1. Watershed area	5389 sq km. (2050 sq mile)	9920 sq km. (3830 sq mile)
2. Annual observed Sediment deposit	15.48(1963) 14.29 (1965)	13.43(1962) 12.38 (1964)

Ham per 100	13.10(1971)	10.00(1974)
1. Less of storage Capacity due to Sedimentation in Percent of area.		
(a) Dead storage space	22%	35%
(b) Life storage space	10%	18%
(c) Flood storage space	Negligible	Negligible

In order to check the sedimentation D.V.C. has already set a Soil Conservation Deptt. who is looking after the sedimentation problem of Damodar river system.

From the sedimentation rate and storage loss capacity in Maithan, Panchet reservoir, it can be seen that during 15 to 20 years impoundment, the Maithan and Panchet reservoirs have already lost part of the live storage due to sedimentation Though initial survey of 1951-59 gave silt deposition rates of less than 3.57ha m / 100 km for all the dam silts except Tilaiya, the actual reservoir survey carried out subsequently revealed that the siltation is much more than expected. The estimates of the years 1965 and 1971 revealed a decreasing in siltation and has been attributed partly to soil conservation measures in the upstream catchment area.

It is clearly evident that the silt load transported by the rivers is appreciable. The useful life of the reservoirs is being reduced year by year gradually. Though the dams have provided to be useful in trapping much of the silt which was progressively rising the bed levels in the river channels. It is therefore necessary that concerted efforts should continue by D.V.C. for more effective soil conservation.

4.15 The Ajoy River

The Ajay river originates from the hills near Deoghar in Jharkhand. The river flowing through States of Jharkhand and West Bengal has a catchment area of 6050 sqkm. Main tributaries are Highlow, Kunoor, Pathro and Jayanti. The lower reach of the Ajoy river is now chocked up with excessive amount of sand/silt deposits. The accumulation of silt deposition in the stream has also resulted in progressive rise in the bed levels of the river Ajoy.

Silt observations are being made at sites: Jamtara & Nutanhat.by CWC.

At Jamtara site it has been observed that total maximum silt load and fine silt load are showing a declining trend while coarse silt and medium silt load do not follow a definite pattern. At Nutanhat site it could be concluded that total maximum silt load as well as coarse, medium and fine silt load are in decreasing order.

4.16 The Jalangi River

The Jalangi originates from the right bank of river Padma in Murshidabad district, 165 km downstream of Farakka and outfalls into Hooghly near Nabadwip in West Bengal. Total catchment area is 5640 sq km. and main tributaries are Sealmari, Bhairab and Suti. Silt data is observed only at Chapra site from 1978 onwards in the Jalangi river system. The nature of silt varies from fine loam to coarse pebbles. The average annual silt load passing through this site is 2.91 million ton.

5.0 BANK EROSION ON GANGA RIVER AND ITS TRIBUTARIES

The north bank tributaries of Ganga by and large (with few exceptions) originate in the Himalayas that are not only perennial but carry huge discharges and large volume of silt as they travel over the steep friable slope of the Himalayan range and avulse into the plains of the Gangetic valley. The huge amount of silt that the river carries induces meandering and braiding of the river channel as also formation of sand bars, thus reducing the carrying capacity of the channel resulting in uneven flow in the river cross section and consequent erosion of river banks.

Loss of land due to erosion had been a scourge to the inhabitants populating the Gangetic valley and several committees and Task Groups have gone into identifying areas prone to erosion by river action and remedial measures for protecting the river banks from erosion have been suggested and anti-erosion measures initiated at enormous cost to the exchequer. A list identifying such areas riverwise is appended for perusal by those interested in the matter.

6.0 SUGGESTIONS FOR REDUCING SILTATION IN THE RIVERS

The average sediment load of mountain fed rivers in Ganga basin is much higher than that of foot hills fed and plains fed rivers which is essentially a function of their catchment areas. They carry high discharge and large quantities of sediment from the friable slopes of the mountain and tend to deposit the same in the lower flatter areas before their confluence with river Ganga causing reduction in channel capacities resulting in extensive overbank spills and consequent inundation.

The basic strategies for controlling the flood flow and sediment within the upper and middle reaches to the possible extent are by (i) constructing reservoirs for storing and regulating the flood and the sediment as well as for comprehensively utilizing the water resources for irrigation, hydropower generation etc. (ii) watershed management to control the entry of sediment into the river (iii) strengthening the levees and carrying out river training works in the downstream reaches of the river and arranging rationally and economically the floodway in the estuary for maintaining the discharging capacity of flood water and sediment to the sea.

6.1 Construction of Reservoirs

Most of the Himalyan rivers which bring heavy silt load in river Ganga originate in Nepal. Suitable reservoir sites are located in the territory of Nepal. A number of water resources development projects benefiting both India and Nepal have been identified and have been under negotiation for a long time. Most of these are storage projects with considerable hydropower potential. Pancheshwar multy-purpose project, Sapt Kosi high dam project Bagmati (at Noonthore) and Kamla (at Tetaria) multipurpose projects are important among them. A joint Committee of Water Resources (JCWR) headed by the respective Secretaries of the two countries has been formed with the mandate to discuss and take decisions on all the important issues pertaining to cooperation in the water resources sector including implementation of the existing agreements and understandings. It also overseas the work of all the technical and expert level committees and groups in the field of water resources, thus act as an umbrella committee of these committees and groups. The Joint Group of Experts (JGE) constituted on Pancheshwar multi-purpose project is responsible for making negotiation with Government of Nepal for all technical matters including investigation and studies relating to Pancheshwar Multipurpose Project. A joint Committee of Experts has also been set up to take up joint studies / investigations as necessary to finalise the parameters of the Sapt Kosi high dam project and to prepare a detailed Project Report at the earliest.

6.2 Watershed Management / Soil conservation

The importance of watershed management in reducing the entry of silt into river and moderating the runoff from the catchment to some extent is generally recognized. Soil conservation measures are greatly instrumental in reducing the silt charge. The latter in high content causes shifting of river courses and consequent erosion of banks and breaches in the embankment. The soil conservation works have to be done in the upper reaches as most of the sediment is brought down into the river from that area. The soil conservation practices recommended for introduction in the agricultural uplands as also in the gullied land include;

(i) Terracing of land by construction of graded bunds with proper water disposal system.
(ii) Land reclamation, development of grass land and afforestation.
(iii) Construction of small to medium check dams/ silt detention dams
(iv) Renovation of silted up old farm ponds
(v) Improved cropping practices based on land capability.

The above soil conservation measures are normally adopted in combination for deriving optimum benefits.

Appendix

LIST OF EROSION PRONE SITES IN GANGA BASIN

A. Main Ganga River

1. Village Sheopur (Right bank of the river , Distt.-Mirzapur, UP)

2. Sherpur village (Left bank of the river , Distt.-Gazipur, UP)

3. Arjunpur and Umarpur(Right bank of the river , Distt.-Buxar, Bihar)

4. Neknam Tola (Right bank of the river , Distt.- Bhojpur, Bihar)

5. Jhauwan Santha village (Left bank of the river , Distt.- Saran, Bihar)

6. Hasanpur, Mahanar block (Left bank of the river , Distt.-Vaishali, Bihar)

7. Amarpur, 3.4 km upstream of Mokama bridge (Left bank of the river , Distt.-Begusarai, Bihar)

8. Karhagola Jarlahi (Left bank of the river , Distt.-Katihar, Bihar)
9. Goagachi (Left bank of the river , Distt.-Katihar, Bihar)

10. Sarakanda Shobhapur reach(Right bank of the river , Distt.-Sahebganj, Bihar)

11. Munger Town(Right bank of the river , Distt.-Munger Bihar)

12. Maharshi Mehi Ashram Reach(Right bank of the river , Distt.-Bhagalpur, Bihar)

13. Kashkol at 6.09 km of 6th retired embankment for length of 450m (Left bank of the river , Distt.-Malda, WB)

14. Daulattola at 3.53 km of 6th retired embankment (Left bank of the river , Distt.-Malda, WB).

15. Khariabona, Alipur(Right bank of the river , Distt.-Murshidabad, WB)

16. Chandrapara(Right bank of the river , Distt.-Murshidabad, WB)

17. Lalpur(Right bank of the river , Distt.- Murshidabad, WB)
18. Lakshminagar under Dhulian Municipality(Right bank of the river , Distt.-Murshidabad, WB)

19. Mahespur & Kakjipara(Right bank of the river , Distt- Murshidabad, WB)

20. Arjunpur(Right bank of the river , Distt.-Murshidabad, WB)

21. Hazarpur & Dipchandpur(Right bank of the river , Distt.- Murshidabad, WB)

22. Mouzakuli(Right bank of the river , Distt.- Murshidabad, WB)

23 Areas in the vicinity of Farakka Barrage.

Left afflux bund of Jangipur barrage in the coyicinity of Moya and Fazilpur village (on right bank of the river (Distt. Murshidabad, WB)

(i) Nayansukh and Beniagram village d/s of Farakka barrage (on right bank of the river Distt. Murshidabad, WB)

B. River Ghaghra

(1) Ayodhya-Bilwahari bund (Left bank of the river Distt. Faizabad, UP)

(2) Raunahi embankment from 0.6 to 0.7 km (Right bank of the river, Distt. Faizabad, UP)

(3) Vikramjot-Dhuswa embankment from 9.4 km to 10.4 km (Right bank of the river , Distt. –Basti, UP)

(4) Sanedi Bund and Sharda Sagar Bund (Right bank of river Sarda, Distt. – Pilibhit, UP)

(5) Kauri Ram Township and Kauri Ram Malauli Bund (on confluence of the rivers Rapti and Aami, Gorakhpur, UP).

C. River Gandak

(1) Amwakhas embankment from 8.7 km to 8.9 km (Right bank of the river, Distt. Kushinagar, UP)

(2) Ahiraulidin-Pipraghat embankment from 1.5 km to 2.2 km (Right bank of the river , Distt.- Kushinagar, UP)

(3) Chtauni embankment (Right bank of the river , Distt. -Kushinagar, UP)

(4) Katai Bharpurwa embankment (Right bank of the river , Distt. Kushinagar, UP)

(5) Koyarpatti, Laukaria and Nagdaba villages (in West Champaran district of Bihar)

(6) Pipra-Piprasi embankment at Buidharwa (in West Champaran district of Bihar)

(7) Saran embankment at Hirapakar village (in Gopalganj of Bihar).

(8) Champaran embankment at many areas on the left bank of Gandak (in East Champaran district of Bihar)

D. River Bagmati

(1) Kangsar-Chandauli villages (in Sitamarhi district of Bihar)

(2) Majhaura village (in Seohar district of Bihar)

(3) Shivajinagar and Mahadewa villages (in Darbhanga district of Bihar)

(4) Kalyanpur village (in Samastipur district of Bihar)

E. River – Kamla-Balan

(1) Jhanjharpur town area (in Madhubani district of Bihar)

(2) Banaur, Thenga and Navtolia villages (in Madhubani district of Bihar)

F. River - Kosi

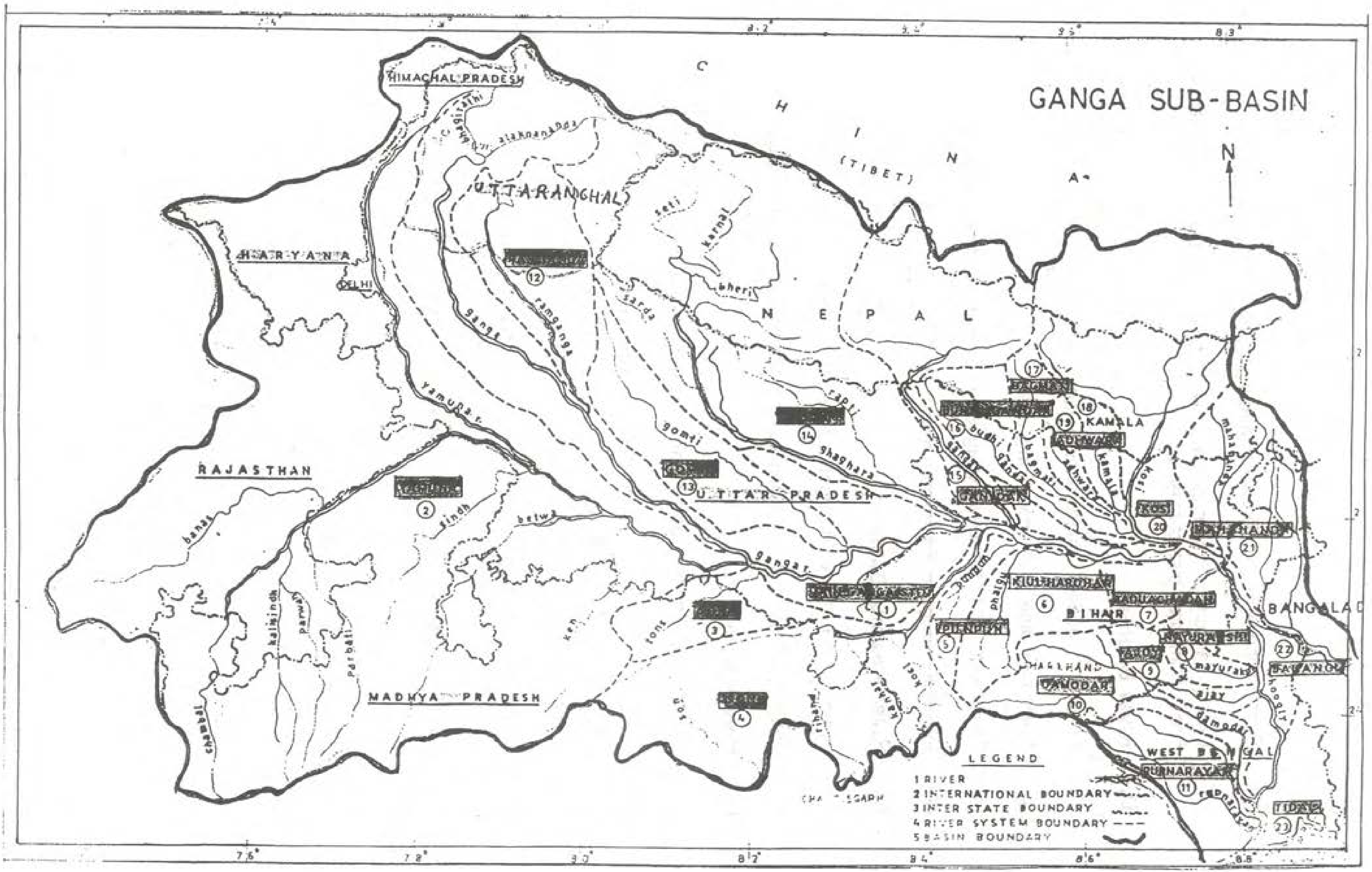
(1) Katiya village on the eastern bank (in Saharsa dist. of Bihar)

(2) Nemua village on the eastern bank (in Saharsa distt. of Bihar)

(3) Mahishi near temple on the eastem bank (in Saharsa distt. of Bihar)

(4) Dagmara village on the Westem bank and Sikrahta – Majhari villages on the same bank (in Saharsa distt. of Bihar)

(5) Kusmol village on the Westem bank (in Saharsa distt. of Bihar)


GANGA SUB-BASIN
N
C H I N A
(TIBET)
N E P A L
HIMACHAL PRADESH
UTTARANGHAL
HARYANA
DELHI
RAJASTHAN
UTTAR PRADESH
MADHYA PRADESH
BIHAR
WEST BENGAL
BANGALADESH
CHATTISGARH
JHARKHAND
ganga
yamuna r.
ramganga
sarda
seti
karnal
bheri
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kanhar
koel
phalgu
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ajay
damodar
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rupnarayan
KOSI
DAMODAR
RUPNARAYAN
TIDAL
LEGEND
1 RIVER
2 INTERNATIONAL BOUNDARY
3 INTER STATE BOUNDARY
4 RIVER SYSTEM BOUNDARY
5 BASIN BOUNDARY
7.6°
7.8°
8.0°
8.2°
8.4°
8.6°
8.8°

PERFORMANCE OF DREDGING OPERATION CARRIED OUT BY IWAI

Inland Waterways Authority of India (IWAI) is undertaking dredging in National Waterways No.1, i.e., in Farakka – Allahabad stretch of River Ganga and by deploying the following type of dredgers:

1 Cutter Suction Dredger

2 Hydraulic Surface Dredger

Besides Manual Dredging was also carried out at some identified locations.

IWAI has improved the navigable depth for navigation in river Ganga considerably and the details of dredging carried out since 1995 are as follows: -

YEAR	QUANTITY
1995-96	0.5 lakh cu.m.
1996-97	1.6 lakh cu.m.
1997-98	1.1 lakh cu.m.
1999-2000	1.1 lakh cu.m.
2000-01	1.5 lakh cu.m.
2001-02	5.9 lakh cu.m.
TOTAL	11.7 lakhs cu.m.

With this, IWAI has been able to maintain 2m LAD in the stretch Haldia – Patna (1000 kms.) and 1.5m LAD up to Ghazipur for a period of 330 days in a year.

Due to the alluvial nature of the river Ganga, annual maintenance dredging / bandalling is required to be carried out for maintaining the navigable channel till semi permanent / permanent River Training measures like construction of Spurs, Guide Walls, Groyans, Dikes etc. are provided for stabilization / rectification of the river.

If 33 lakh cu.m. of dredging could be carried out annually, it is possible to maintain 2m LAD up to Patna and 1.5m up to Allahabad for 330 days in a year. As per past experience of IWAI, once dredging is carried out, the navigational channel can at best be maintained for that season, and some shoals dredging may have to be redone even in one season.

A report on "Comprehensive Requirement of Hardware & Software for maintaining 2 m Depth in three National Waterways" prepared by Cdr.R.M.Nair is enclosed for further necessary reference. (for navigability refer page 2 and for dredging refer page 4-8 & 9-14 of the report).

SOIL CONSERVATION MEASURES BY DAMODAR VALLEY CORPORATION

It was envisaged in the original project plan for the Unified Development of Damodar Valley to provide flood control storage capacity of 2.90 million acre feet and conservation storage capacity of 2.30 million acre feet by construction of seven storage dams at different locations of the basin. The project was to be executed in two stages of which only the first stage of construction was completed by 1959 with the construction of four dams, viz., Tilaiya, Konar, Maithon and Panchet. In the first stage, provision was made for 1.22 million acre feet of flood control storage capacity and 0.98 million acre feet of conservation storage capacity. During the last 43 years after completion of the first stage of construction, reservoir storage capacity has reduced substantially on account of sedimentation and the available conservation storage capacity at present in only in the order of 0.73 million acre feet. To combat the reservoir sedimentation soil conservation measures are being taken continuously by DVC since its inception.

SOIL CONSERVATION ACTIVITIES IN DVC :

As a part of corporate objective, Damodar Valley Corporation had established the department of Soil Conservation in the year 1949 to deal with the problems of conserving the soil over the entire upper catchment which covers an area of 17.51 lakh hectares. The work of soil conservation and afforestation are carried out with one of the main objective to control the soil erosion in the valley so that siltation rates in the DVC dams are reduced.

For the purpose of planning and execution of soil conservation works, an aerial survey of the entire upper catchment was carried out followed by rapid reconnasation and aerial photo interpretation. The survey report revealed that a denuded forest land of 4.83 lakh hectares, an agricultural upland of 3.98 lakh hectares and gulled waterland of 2.66 lakh hectares were suffering from different degrees of erosion requiring urgent intervention. Further, these areas were prioritized based on their degree of sufferings on the basis of guidelines of Govt. of India, Department of Agriculture in 1991. Till 2000-2001, afforestation has been done by DVC over an area of 1.91 lakh hectares out of 2.47 lakh hectares of priority problem area. This includes plantation in non-agricultural and denuded forest land, protection of forests, regulation of grazing etc. Upland treatment of 2.522 lakh hectares has been done out of 22.77 lakh hectares of priority problem area. This work involves terracing by construction of graded bands, land reclamation, construction of small water harvesting sediment control structures in the gulled agricultural land and demonstration of Improved crop management practices based on land capability. Out of 2.03 lakh hectares priority problem areas, wasteland treatment work has been done in 0.896 lakh hectares area. This work includes construction of chain of silt and water detention structures to reduce the velocity of the run-off in the gullies and their peripheral region and thereby minimize its silt carrying en-route to the main waterway.

LOSS OF CAPACITY IN DVC RESERVOIRS DUE TO SEDIMENTATION

The Damodar Valley Project was originally envisaged as an integrated one and the storage capacities were accordingly allocated having upstream dams in view. All the upstream dams have not been constructed as originally planned. The high percentage -- --------------------- allocated zones now point out to the fact that in an integrated plan like that of DVC, the construction of upstream reservoirs should not be unduly deferred. A chart showing the decrease in capacities of Maithon and Panchet reservoirs for different zones are given below :-

PROGRESSIVE SEDIMENTATION IN DVC RESERVOIRS

A. MAITHON RESERVOIR **(Capacity in '000 ac ft.)**

Capacity of Maithon Reservoir in different zones :
(for Surveys conducted in different years)

Zones	**Original (1955)**	**Year of Survey**					
		(1963)	**(1965)**	**(1971)**	**(1979)**	**(1987**	**(1994)**
Dead zones (upto El. 435 ft)	167.4	140.4	135.5	130.8	112.5	95.1	76.9
Live zone (EL435-480 ft)	492.3	465.3	461.0	441.5	425.3	398.5	381.8
Flood zone (EL 480 – 495 ft)	309.8	312.6	313.2	308.7	306.4	301.7	296.5
Over all (Upto EL. 495 ft)	969.5	918.3	909.7	881.0	844.1	795.2	755.2

Loss of Capacity and percentage w.r.t. Original capacity
(for Surveys conducted in different years)

Zones	**Original (1955)**	**Year of Survey**					
		(1963)	**(1965)**	**(1971)**	**(1979)**	**(1987**	**(1994)**
Dead zones (upto El. 435 ft)		27.0 16.2%	31.9 19.0%	36.6 21.9%	54.9 32.8%	72.3 43.2%	90.5 54.0%
Live zone (EL435-480 ft)		27.0 5.5%	31.3 6.4%	50.8 10.3%	67.1 13.6%	93.8 19.1%	110.5 22.4%
Flood zone (EL 480 – 495 ft)		Negligible		1.1 0.3%	3.4 1.1%	8.1 2.6%	13.3 4.3%
Over all (Upto EL. 495 ft)		51.2 5.3%	59.8 6.2%	88.5 9.1%	125.4 12.9%	174.2 18.0%	214.3 22.1%
Sediment deposit Rate(acft./Sq.Mile/ Year)		3.2	3.0	2.8	2.6	2.7	2.7

Further it is studied that, if a small dam at Balpahari, upstream of Maithon dam, is introduced in the system which was included in the original plan, the rate of sedimentation in the Maithon reservoir would be drastically reduced, hence the useful life of Maithon would be extended by about 60 years or so besides benefits of irrigation, water for municipal and industrial purposes and hydel power generation from the storage of Balpahari dam.

The reservoir capacity survey of remaining two reservoirs, viz., Tilaiya and Konar are not done at regular Intervals, as it is done for Maithon and Panchet reservoirs. The following tables indicate the capacity and loss in storage at Tilaiya and Konar reservoirs in different zones for surveys conducted during its inception (original survey) and surveys conducted in the year 1997.

C. TILAIYA RESERVOIR **(capacity in '000 ac ft,)**

Capacity and Loss in Storage of Tilaiya Reservoir in different zones :
(for Surveys conducted in 1997 vis-à-vis original)

Zones	Original survey	1997 survey	Loss in	
			Storage	% age
Dead zones (upto El. 1192 ft)	61.0	60.6	0.4	0.66
Live zone (EL1192-1210 ft)	114.0	113.9	0.1	0.09
Flood zone (EL1210-1222 ft)	145.0	134.1	10.9	7.52
Over all (Upto EL. 1222 ft)	259.0	248.0	11.0	4.25

D. KONAR RESERVOIR **(Capacity in '000 acft,)**

Capacity and Loss in Storage of Konar Reservoir inn different zones
(for Surveys conducted in 1997 vis-a-vis Original)

Zones	Original survey	1997 survey	Loss in	
			Storage	% age
Dead zones (upto El. 1347 ft)	49.0	28.0	21.0	42.86
Live zone (EL1347-1397ft)	179.0	142.0	37.0	20.67
Flood zone (EL1397-1401ft)	44.0	31.0	13.0	29.55
Over all (Upto EL. 1222 ft)	223.0	173.0	50.0	22.42

No. 3/25/2001-Morpho/
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 31.12.2001

Sub:- First Meeting of the Committee to study the Problem of Silting in Indian rivers.

First meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 10.01.2002 at 11.00 hrs. in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. All the members are requested to kindly make it convenient to attend the meeting. A brief background paper has been prepared on River Siltation which is to be sent shortly. The members may prepare article/material relevant in this regard and hand over during the meeting.

The agenda of the meeting is noted below :-

1. Chairman's address
2. To discuss and decide theh modus operandi to carry out the assigned task.
3. Identification of special studies, if required, to be carried out and required data.
4. Any other item with the permission of the Chair.

Kindly confirm regarding participation in the fifth meeting.

Thanking you,

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

No. 3/25/2001-Morpho/6-9
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 2.1.2002

Sub:- First Meeting of the Committee to study the Problem of Silting in Indian rivers.

In continuation of letter no. 3/25/2001-Morpho/796-809 dated 31.12.2001, enclosed please find herewith the brief background paper on River Siltation for kind perusal and furnishing comments, if any.

Wishing a happy new year and thanking you.

Yours faithfully,

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax No. 6102267

RIVER SEDIMENTATION – PART I

1.0 BACKGROUND

There are numerous rivers in India. Floods and droughts are often experienced. 40 million hectares of land is flood prone and protection has been provided to about 15 million hectares of land against floods. Flood protection has been provided by structural methods such as embankment, flood storage, channel improvement, detention basin, etc. Flood embankment has been bedevilled with controversies dating back even from nineteenth and early twentieth centuries. The Rashtriya Barh Ayog report has dwelt upon the subject in details. In its final conclusion, it has recommended the construction of embankment subject to proper design, construction, maintenance, etc. There is an impression that embankment inter alia induces siltation in a river course which is yet to be quantified conclusively in different river courses.

2.0 RIVER SYSTEM IN INDIA :

River basins in India have been divided into three categories mentioned as below :-

(a) **Large basins** : Twelve (12) river basins having catchment area 20,000 sq.km. or above.

(b) **Medium river basins** : Forty eight (48) river basins having catchment area between 2000 sq.km. and 20,000 sq.km.

(b) **Minor river basins** : River basins with catchment area below 2,000 sq.km.

The major river basins form 83% of the total drainage area and together with the medium river basins cover about 91% of the total drainage area.

3.0 EROSION

Soil erosion is a nature's phenomenon going on since time immemorial. It is also a part of land formation. Alluvial plains have been created due to erosion that occurred millions of years before. Alluvial plains have been very fertile as water from upstream brings with it silt, which when spread on agricultural land, enhances its fertility.

Following factors affect land erosion.

3.1 Topography :

Topography exerts diversified effects on soil erosion. The first is the difference of the land surface. Himalayan rivers have catchments which include hilly areas of Himalayas as well as plains of north India. Kosi river, for example, debouches to north Bihar plains abruptly. Second is the relief of land surface, causing more erosion if it is more uneven. The third is the surface slope. In case of steep slope more erosion takes place compared to erosion in mild slope. In rivers of North India, slopes in upper catchment are steeper while those on lower catchments are milder, causing thereby erosion upstream and siltation downstream.

3.2 Soil Properties : Stability of erosion resistance of soils depends upon the mechanical texture, physiochemical properties and chemical elements and the natural state of surroundings. Cohesionless soils of alluvial plains are more susceptible to erosion.

3.3 Climate : Climatic conditions affect soil erosion. Variation of temperature makes earth surface to undergo cooling and heating process resulting in brittleness of surface.

3.4 Vegetative Cover : Forest and grassland possess significant water retaining capacity. They can promote normal water circulation and play an important role to conserve water and control surface runoff and prevent soil erosion. Forest generally has a multi layer structure, absorbs at top layer, shrubs at medium layer and grasses on ground surface. Moreover, there is developed root system beneath the ground water surface. The canopy can intercept rainfall up to 20%. The densely grown grasses and fallen leaves can intercept rainfall considerably. Root system of trees and grasses in combination with the crumb-structure of the soil can facilitate the seepage, so that most of the rainfall can infiltrate into the soil and can be transferred into ground water flow. Therefore, the quality of recent vegetative cover is directly related to the status of soil erosion. Vegetation is found effective in reducing low floods. However, its impact on large floods is not so pronounced.

3.5 Tillage practice : Excessive exploitation of land resources such as reckless cultivation poor management and irrational agricultural structure, together with over population beyond the environmental capacity are man made factors accelerating soil erosion. In North East India, the practice of Jhum cultivation, prevalent in hilly area causes soil erosion enormously.

The above-mentioned factors contributing to soil erosion may be summarized as follows. The first is the surface gradient and the length of slope; the second is the amount and intensity of rainfall; the third is the texture, chemical elements and the physiochemical properties of the soil and the natural state of soil surroundings; the fourth is the vegetative cover and the fifth is the tillage practice. The first two items depend on the natural conditions and the last two items mostly depend on human activities, while the third item depends on both. The human activities can in turn influence the effects of natural conditions. All the five factors are interrelated and function together to determine the amount of soil loss and the severeness of erosion.

4.0 SILTATION

The natural corollary of soil erosion is silt load in a river. The soil that is eroded finds its way in the flowing water of a river. River cross section is subjected to erosion and siltation by flowing fluid depending upon hydraulic and hydrologic characteristics covered under Silt Transport Theory. Construction of dam reduces the velocity of water in upstream thereby causes siltation in the reservoir. The silt free water, released through spillway, causes erosion downstream of the spillway along its length. Siltation can be broadly divided into two parts:-

1. Reservoir siltation
2. River bed siltation

The palpable consequences of reservoir sedimentation is almost ubiquitous, requiring no special mention.

River bed sedimentation on the other hand is not clearly visible as it is a slow process and not monitored regularly. Natural phenomena such as earthquakes, landslides do accelerate river siltation appreciably resulting change in morphology of the river.

Siltation in a river starts from its source. When the river emerges out of the mountain gorge and enters the valley, the slope suddenly flattens, velocities get reduced and flowing particles settle to river bed. Further downstream river follows either meandering or braided form depending on silt content. Brahmaputra river is said to be of meandering nature in the past. However, Brahmaputra is presently a braided river in the plains of Assam.

Continuous siltation is dangerous as it may lead to spill flow laterally and in extreme case may cause avulsion. To obviate such a situation, regular monitoring is required. Siltation i.e. aggradation brings about changes in the river configuration, especially the longitudinal bed slope. Aggradation in one reach is followed by degradation in the next reach. Thus aggradation and degradation alternatively occur in a river reach. A study by GFCC in Kosi river in 1980 was conducted to ascertain the aggrading/degrading nature. The entire reach from Birpur to its outfall into river Ganga was divided into six segments. The result of the study indicated aggradation in four reaches and degradation in two reaches. A similar study by D.C. Goswami for the period from 1957 to 1971 in the upper reach of 145 km length in Brahmaputra between Kobo and Bessamara indicated similar results. To carry out aggradation-degradation study, D.C.Goswami divided the Kobo-Bessamara reach of Brahmaputra into 15 segments. Results for period from 1971 to 77 indicated degradation in initial three segments, followed by aggradation in next two reaches. Subsequent four reaches indicated degradation. The last two segments indicated degradation and the rest four aggrading nature. Thus average rate of aggradation may not reflect the true picture. To figure out the real position, survey has to be carried out immediately following the end of the monsoon season. The study concerning to silt deposition/erosion ought to be carried out at a few specific locations before the ascertainment of overall view of the whole reach of a river.

4.1 Silt Load in Indian Rivers : Central Water Commission has recently conducted a study to find out the silt load i.e. quantity of silt carried by river water to sea. Silt data for last 10 years for all the major rivers were considered to work out average annual sediment load of each basin in the country. It was found that on an average 1066 million tons of sediment is carried to the sea every year by our river systems.

4.2 Assessment of siltation : There are several methods which could be employed to assess siltation in a river bed. Silt content is worked out on the basis of silt data that are collected at discharge observation sites.

Aggradation/degradation is assessed by cubature method or specific discharge gauge curve as explained below.

4.2.1 Cubature Method : This is positive and direct method of finding out aggradation/ degradation in a river reach. Study is carried out for a specific reach of a river and for specific period. The cubic contents of deposition are worked out. Positive deposition indicates aggradation whereas negative value indicates degradation.

4.2.2 Specific discharge-gauge curve : This is indirect method of assessing aggradation. The rise of water level for the same discharge in the period under consideration indicates aggradation at the specific location e.g. for the same flood discharge, the water stage of Yellow river in 1985 was higher by about 1.0 to 1.8 metre than the water stage of 1958 of the river.

4.2.3 Embankment and Aggradation : Embankment is a method of flood control which has been adopted universally by all flood affected countries. Prior to 1954, there was a few flood embankment in the country mainly constructed and maintained by local people or individuals. These embankments known as Zamindari Embankments were not properly designed and constructed. Nevertheless, they continued to exist even after 1954 when India began to take protection measures to control flood. Flood embankments were constructed in late fifties and sixties. Till date embankments have been constructed along almost all the rivers. Embankments were initially constructed with a view to affording prompt and immediate relief to flood affected people. Other measures were expected to follow towards finding permanent solution. Embankments along Kosi were completed in 1963 with the hope that in due course of time, the dams in the hilly region in Nepal would come up. Likewise, dams were expected in Brahmaputra basin. Construction of dams across a river does not control flood water alone but also it controls silt load which is the chief cause of river shifting tendency. In D.V.C. project, the construction of dams has reduced the flood menace in Damodar river considerably.

The natural river course would drop extra silt on flood plain as a result of reduced velocity of flood water. Thus silt would be spread on flood plain which would act as natural manure. Embankment construction entails cutting the flood plain area which hitherto was the playground for the swollen river. Confining river course between embankments prevents silt from spreading on total flood plain area thereby making silt to cause aggradation/degradation of river bed. It does not imply that aggradation occurs in embanked rivers only. Even otherwise aggradation takes place. The process is somewhat accelerated when river is embanked from both sides.

2.0 AGGRADATION IN CONTEXT OF YELLOW RIVER OF CHINA :

Yellow river is often cited for its unique characteristics. The unique features of the Yellow river are :

1. The river regulation work continues, at least, for about last 4300 years without interruption;

2. The deposit of the special soil, loess covers one quarter of its drainage area (200,000 sq.km.) with depth varying from ½ to 300 m (compared with 40 miles along the Mississippi and also about 200 km along the Danube in Europe);

3. The silt load transported by river current amounts to 46% (even 50% on its tributary, the River Lo) by weight ;

4. The lower river course acts like a flume elevated above the general ground level by 2 to 7 ½ m, with width varying from 6.5 to 13 km for a distance of 650 km.

Yellow river is famous for its shifting nature and has changed its course 1582 times during last 4200 years, 6 among them being major ones.

The Yellow river has a total of 5464 kms length with 752,000 Square km. drainage area. The river is divided into three parts – upper, middle and lower. The lower Yellow river channel is 770 km long with gentle channel gradient. This river reach has been embanked from both sides and there is enormous amount of silt deposition in this portion so much so that the river is called a suspension river.

The basic strategies for controlling the lower Yellow River are "flood storage in the upstream, flood release in the downstream, and flood diversion and detention outside the two banks"

1. to control the flood flow and sediment within the upper and middle reaches to the possible extent by constructing reservoirs for storing and regulating the flood and sediment as well as for

comprehensively utilizing the water resources for power generation, irrigation, etc.

2. to actively push towards the measures of water and soil conservation in the middle reaches in combination with the demand of local production, especially to focus on controlling the areas that produce extensive sediment and coarse sediment which exert greatest influence on the sediment in the downstream river bed;

3. to strengthen the levees and carry out river training works in the downstream river reaches and to arrange rationally the floodway in the estuary for maintaining the discharging capacity of flood and sediment to the sea;

4. to open the flood diversion and detention basins outside the two banks of the lower river reaches for handling the over-standard floods in the river course;

5. to strengthen the non-engineering measures for reducing the losses caused by extraordinary floods to the greatest possible extent.

6.0 CONCLUSION

There is an impression that rise of flood level is due to siltation in river bed which has reduced the carrying capacity of river. In Cauvery delta, there was siltation in channels causing congestion to water flow. Desilting for a depth of 0.6 m to 1.5 m in these channels has been accomplished with the help of machinery during the closure period. A report on the same is enclosed for reference. In India, systematic morphological study is required to understand the river behaviour which may be utilised subsequently. There are plethora of articles by several persons especially non-Governmental agencies who frown upon the efficacy of embankment. Embankment has been constructed out of exigency and planners must have envisioned the consequences stemming from the morphological changes in a river. Study has to be carried out about siltation vis-à-vis flood level in a river. Possible solution including dredging may be examined. Dredging for reservoir, though practicable, has been ruled out by CWC mainly from economic consideration. Will it not be worth considering to raise embankment height, taking cue from Yellow river in China ? Another potent step could be to check silt entry into river courses. The situation at present may not be that much alarming. Thorough scientific study, followed by pre-emptive measures may be required in this regard.

Over the years silting of rivers has also assumed serious proportions. The matter also came up for discussion during the meeting of the Standing Committee on Agriculture on the Demands for Grants (2001-2002) as well as Parliamentary Consultative Committee of the Ministry of Water Resources. Accordingly, MOWR, Govt. of India has set up a Committee to study and report on the problem of silting in rivers and related aspects including feasibility of desilting. The terms of reference of the Committee are as under:-

1. To identify cause and extent of siltation in rivers.
2. To suggest measures to minimize siltation.
3. To examine whether desilting is a technically feasible means to minimize magnitude of floods in rivers.
4. To suggest appropriate technology/methods of desilting of rivers if found technically feasible.
5. To find economic viability of desilting of rivers.
6. To propose a realistic operational programme in a time bound manner.
7. Any other related aspect.

Minutes of the First meeting of the Committee to study the problem of silting in Indian rivers held on 10th Jan. 2002 in the Committee Room of the Member (RM), CWC, Sewa Bhawan R.K.Puram, New Delhi - 110066

Dr. B.K.Mittal, Chairman of the Committee welcomed all the members and wished them a Very Happy New Year. The list of members of the committee and other concerned officials present in the meeting is enclosed (Annex-I).

The Chairman apprised the members about the background behind the formation of this committee. The main objective of the committee is to look into the silting problem of rivers in the country. He stated that in India no systematic scientific study on the silting problem of the rivers has been carried out except for few reaches in rivers Brahmaputra and Kosi. There is general perception that due to silt deposition river bed is rising therby resulting in reduction of flood carrying capacity of river. He also informed that there is a suggestion to carry out desilting operation in certain problem prone rivers and the silt thus removed may be used for construction of embankment along the bank of river.

The Chairman requested the Member Secretary to introduce the subject and present the background note prepared and circulated to members. The Member Secretary apprised the members of river siltation problem in India specifically mentioning Cauvery Delta where desilting operation has been carried out in the years 1997, 98, 99. He subsequently explained the terms of reference of the committee to the members. Shri A.K.Chakraborty, NRSA, Hyderabad, while intervening, suggested for identification of rivers and affected reaches where aggradation problem is being felt.

Thereafter, Member Secretary introduced the agenda items for detailed discussion.

1.0 DISCUSS AND DECIDE THE MODUS OPERANDI TO CARRY OUT THE ASSIGNED TASK.

1.01 The Chairman explained that the primary responsibility of the committee is to identify the cause and extent of siltation in Indian rivers and to suggest measure to minimise siltation. He requested all the members to express their views on the issues.

1.02 Shri Basu from Government of West Bengal stated that siltation is a natural phenomenon and it may have been affected by human interference. No scientific studies have been carried out to find out the extent of siltation in Indian rivers except Brahmaputra and Kosi rivers. He stressed upon the need to compile the studies on river siltation in Indian rivers. He mentioned that Government of West Bengal had carried out siltation study in river Bhagirathi but the report could not be circulated on account of secrecy. He, however, agreed to send a copy to the Chairman. In West Bengal tidal rivers are badly affected by siltation. Water Resources Development, Irrigation practices and flood control activities aggravate siltation problem. He cited example of DVC system due to which water level of Rupnarayan and Hooghly river system have gone down causing siltation in the river bed. This happens because of the fact that during lean season water is drawn for irrigation purpose. He emphasised that the balance approach of flood control and Agriculture requirement need to be studied in depth. He suggested to carry out reach wise river system study for some rivers as done for Brahmaputra and Kosi. Data with regard to siltation need to be collected. He also informed that desilting operation in West Bengal was carried out in the past, the result of which had not been very encouraging. Shri Basu stated that desilting operation entails disposal of silt which is a big problem. Disposal necessitates land to dump the silt which is difficult to find in nearby area. He cited example of Ichhamati river where desilting operation could not materialise for want of suitable land for silt disposal. However, selective dredging is necessary especially in tidal rivers, to remove congestion and to facilitate the passage of flood.

Mr. Basu was requested to submit a report from Government of West Bengal in regard to desilting operation carried out in West Bengal.

1.03 Mr. A. Hayat, Engineer-in-Chief, Government of Bihar narrated the consequences of river bed siltation in North Bihar rivers like Kosi, Gandak, Kamlabalan, etc. In Gandak, even smaller discharge which was safe in the past is causing problem in the plains of Bihar. It is because of the fact that siltation has taken place and carrying capacity of river has been reduced. In Kamlabalan, siltation is so severe that river bed is risen to 4 meters above the general ground level. Kosi has migrated about 112 kms from east to west during last 246 years. He also informed that river slopes of north Bihar rivers undergo a steep decline while entering to the plains from Nepal. He, however, did not present any specific study to corroborate the above statement.

The Chairman wanted to know from the representative of Bihar Government about the status of siltation study carried out by State government especially in Kosi river.

1.04 Mr. Ghatak, IWAI informed the members about desiltation carried out by IWAI for navigation purpose in Ganga, Brahmaputra and other rivers in Kerala. He mentioned the problem of siltation at the mouth of upstream Navigation lock in Farakka Barrage for which mathematical model study has been proposed. The Chairman wanted to know the experience of Inland Waterways Authority of India regarding desilting operation from Patna to Farakka.

1.05 The representative from GSI stated that the dredging is not a solution instead we should try to identify the siltation problem in upper reaches and find out a solution to stop sediment load coming to the river.

1.06 Shri B.C.Nayak participating in the discussion informed the Committee about the problem being faced by Orissa due to tidal effect near the mouths of the rivers. He stated that the silt deposition in tidal rivers leads to drainage congestion in areas near the mouth of the rivers. The mouth of the river in the sea should be desilted once in 10 years to keep it in good hydraulic conditions. He suggested to construct a few pilot channels to push water in the river to wash out the silt from the rivers. Some natural process can be tried to clean the mouth. He informed that in Orissa, some vulnerable reaches were desilted but without any success. He expressed that desiltation is very costly method and may not be economical. Instead of desilting, the whole river should be jacketed. He suggested that to minimise the siltation the following measures may be taken

i) The flow of sand by littoral drift along coast line should be diverted away from the mouth of the rivers,
ii) Large scale afforestation should be taken up
iii) Obstructions to the natural flow of water to be removed
iv) Design waterway to be provided in the river

According to him, Government of Orissa had sponsored a study which was conducted by I.I.T. Madras who recommended desilting operation. The State Government, however, could not act on the recommendation due to paucity of funds.

1.07 Prof. Sivasami, JNU drew the attention of the members about flood problems in rivers outside India. He mentioned that in 90s the Mississippi river in USA, Rhine in Europe, rivers in New South Wales of Australia, Argentina, and China have caused devastating floods in their respective areas. He stated that river is a dynamic system and it cannot be tamed arbitrarily. One has to understand river mechanics in order to avoid adverse situations. Many problems have arisen because of faulty implementation of flood control schemes. According to him, this is a man made problem and could be avoided had the natural river flow been understood. There is a false impression that river can be controlled. He said that in a river system when one reach is affected by siltation the other reach is affected by scouring. He informed the committee that the Ministry of Environment is formulating a scheme to evolve the use of river bed. He emphasised that desilting may be carried out as a pilot project before embarking upon the scheme for the whole country.

1.08 Shri A.K.Chakraborty from NRSA stated that the root cause of flood problem is siltation and wanted to know the extent of river siltation in Indian rivers. He suggested to identify the rivers and river reaches having siltation problem. He stated that the information on the existing river training works and also low lying areas and drainage congestion need to be collected for proper study. He informed the members that NRSA has prepared river maps of some important rivers which could be provided to the committee for perusal and reference. He indicated that Remote Sensing study may be useful to find out low lying area, water logged area etc. Dredging may be carried out after model study in some selected reaches of rivers. He stated that the siltation is also caused by vegetation and tillage practices. He cited the example of Tawa and Baghari dams in Madhya Pradesh where there is great difference regarding the degree of siltation in reservoirs. CWC, according to him, has sufficient data which could be utilised to work out the extent of siltation in Indian rivers and reservoirs. He suggested for catchment treatment method whereby catchment is managed to yield minimum silt and also changing of agricultural practices to reduce the silt deposition in the river beds.

1.09 The Chairman, Brahmaputra Board suggested for desilting operation in Brahmaputra river to reduce flood level in selective manner. He wanted a study to be made for river Brahmaputra from the reach from Tejpur to Guwahati to find out whether the river could be confined by embankment. He also suggested for taking up pre-siltation measures like catchment area treatment etc. He informed that in river Brahmaputra it has been observed that no silt deposition has taken place on the river bed in 3 km u/s and 3 to 4 km d/s of bridges near Guwahati.

2.0 IDENTIFICATION OF SPECIAL STUDIES, IF REQUIRED TO BE CARRIED OUT AND REQUIRED DATA

2.01 Prof. Sivasami from JNU stressed upon understanding of river behaviour. He suggested to identify river reaches where the siltation problem is existing. He also wanted the informations from different sources need to be compiled. It was also decided to enquire from other organisations who have conducted study in this regard.

2.02 The Chairman sought the opinion of the members regarding field visit of the team to ascertain the cause of siltation and effect of aggradation/degradation in the river. A proposal of field visit in Brahmaputra Basin was suggested by the Chairman, Brahmaputra Board, but no decision had been taken on this issue. On the issue of special studies, it was felt that it would be better to collect all the available documents/materials with different agencies involved in studying the siltation problem in the Indian rivers. Accordingly, it was decided to approach Soil Conservation Div. of Ministry of Agriculture, DVC, Hydraulic Deptt. of Calcutta Port Trust, River Institute of West Bengal, National Institute of Hydrology, Roorkee and North East Hydraulic Research Institute, Guwahati for obtaining necessary information and results of studies which they might have carried out on river siltation. It was informed in the meeting that Andhra Pradesh Government has carried out dredging operation in Godavari Delta to remove the siltation problem in affected areas. It was decided that The Government of Andhra Pradesh may be requested to forward a report of the same for the perusal of the Committee.

3.0 It was decided by the Committee to co-opt a member from NIH, Roorkee as the institute and its regional centres are carrying out the R&D work in the field of sedimentation.

4.0 ANY OTHER ITEM

The Chairman sought opinion of members on the issue of technical feasibility of desilting to minimise the magnitude of floods.

4.01 Shri Basu from Government of West Bengal informed the committee that dredging does give some relief in a small reach, effect of which is negated within 10-15 years. He stated that dredging is economically, technically feasible only for removing drainage congestion. He said that at times dredging may be done selectively. He mentioned also about silt harvesting pond which could trap extra silt in a river.

4.02 Sh. B.C.Naik informed the Committee that dredging of extra silt from the river bed is very expensive proposition. He also stated that the dredging is not a permanent solution, as the reach which has been dredged to remove extra silt will be silted up again within few years time.

5.0 The Committee decided to have the next meeting in the last week of February 2002 after collecting the reports/materials on the subject from different organisations.

The meeting ended with a vote of thanks to the Chair.

LIST OF PARTICIPENTS WHO ATTENDED THE FIRST MEETING OF THE COMMITTEE ON 10.01.2002

1. Dr B.K.Mittal, Ex Chairman, CWC	Chairman
2. Sh. S.K.Das, Member (RM), CWC	Member
3. Sh. K.D.Saharia, Chairman, Brahmaputra Board	Member
4. Sh. A.Hayat, Commissioner & Secy. Govt. of Bihar	Member
5. Sh.P.K.Basu, Secretary, Irr. & Waterways, Govt. of W.B.	Member
6. Sh. A.K.Chakraborty, Group Head(WR), NRSA	Member
7. Sh. A.R.Ghatak, Hydrographic Chief, IWAI	Member
8. Dr. Y.P.Sharda, Director, GSI	Member
9. Sh. K.S.Sivasami, Professor, JNU	Member
10. Sh. B.C.Nayak, Former Engg.- In- Chief, Govt. of Orissa	Member
11. Sh. S.K.Sengupta, Chief Engineer, P&D Orgn., CWC	Member Secy.
12. Sh. Gorakh Thakur, Director, Morphology Dte. CWC	Sp. Invitee

No. 3/25/2001-Morpho/248-62
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 14.3.2002

Sub:- Second Meeting of the Committee to study the Problem of Silting in Indian rivers.

Ref:- MOWR's letter No. 2/11/2000-ER/4285-4311 dated 8.10.2001.

Second meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 05.04.2002 at 11.00 hrs. in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. All the members are requested to kindly make it convenient to attend the meeting. The members may prepare article/material relevant in this regard and hand over the same to the Chairman, Dr. B.K. Mittal during the meeting.

The agenda of the meeting is noted below :-

1. To confirm the minutes of the first meeting held on 10.1.2002
2. Progress of the studies carried out till now and review of material received from members.
3. To discuss the brief outline of the draft report.
4. Any other item with the permission of the Chair.

Kindly confirm regarding participation in the fifth meeting.

Thanking you,

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

Minutes of the Second meeting of the Committee to study the problem of silting in Indian rivers held on 5th april 2002 in the Committee Room of the Member (RM), CWC, Sewa Bhawan, R.K.Puram, New Delhi – 110066

Dr. B.K.Mittal, the Chairman of the Committee welcomed all the members and requested Shri Suresh Chopra from GSI, Capt. Rao from Dredging Corporation of India, Vishakhapatnam and Dr. Shitole from CWPRS to introduce themselves as they could not attend the first meeting held on 10th January, 2002. Dr. K.K.S. Bhatia, Co-opted Member who could not attend the first meeting also introduced himself to committee. He further requested the Member-Secretary to inform the members on the present status of the activities in brief. The list of members present in the meeting is enclosed. (Annexure – I)

1.0 CONFIRMATION OF MINUTES

Shri S.K.Sengupta, Chief Engineer, CWC and Member Secretary of the Committee on silting of Indian rivers informed that the minutes of the Ist meeting of the Committee were circulated to all the members for their information and comments. As no comments have been received from any body, he requested the members to confirm the minutes of the first meeting, circulated earlier. The members confirmed the minutes of the first meeting without any modification.

2.0 PROGRESS OF THE STUDIES CARRIED OUT AND REVIEW OF THE MATERIAL RECEIVED FROM MEMBERS

2.01 As desired by the Chairman, Dr.B.K.Mittal, the Member Secretary presented a brief review of the literatures/studies that have been received/collected concerning to silting of Indian rivers. The members were informed of the report prepared by I.I.T., Chennai on silting of coastal rivers in Orissa. The Member Secretary subsequently read out the recommendations suggested by Shri B.C. Nayak towards solution of silting problem in his paper on "Status of Silting in rivers of Orissa". He also informed in the meeting about the note on river Brahmaputra submitted by Shri A.K.Chakraborty, NRSA, Hyderabad.

The Committee was informed about the paper submitted by the Secretary, Flood Control, Government of Assam on silting of rivers in north east and remedial measures, the report from DVC and the article by Shri Rajiv Sinha, I.I.T., Kanpur on silting/flooding of North Bihar plains. The copies of all the papers received by the Member-Secretary were handed over to the members.

2.02 Capt. M.V.Rao, Dredging Corporation of India gave a brief outline on silting of rivers and viability of dredging operation. He informed the committee that artificial construction causes siltation. He stated that the dredging of river bed is a costly method and other alternatives like river training works, watershed management etc. may be thought of. He suggested that before recommending any measure, we should try to find out the solution through Mathematical Modeling. The dredging by Calcutta Port Trust was also mentioned in this context. There are some non-perennial rivers where dry excavation can be carried out. The Chairman, thereafter, sought the experience of Dredging Corporation of India on desilting of rivers as a viable alternative to reduce flood impact. Capt. Rao informed the members that the issue should be understood in a macroscopic way. Extensive study should be carried out before taking any decision on the issue. He also informed that dredging may not have lasting solution to the problem.

2.03 Mr. A.R. Ghatak from IWAI informed the committee that dredging is not a permanent solution as far as the experience of their organization is concerned as they have to carry out dredging operation every year.

2.04 Dr. K.K.S. Bhatia, Scientist "F" from NIH, Roorkee suggested to prepare a comprehensive report comprising elements relating to silting of rivers. This will require time and as such he suggested for extending the tenure of the committee at least for 6 months. He also suggested to prepare a tentative draft report incorporating experiences of State Governments and other agencies. A questionnaire according to him, should be prepared and circulated to all concerned for collecting their views. Dr. Bhatia advocated to incorporate environmental aspect while studying the problem and suggesting remedial measures.

2.05 Dr. Shitole from CWPRS informed the committee that CWPRS has carried out morphological study and published the following reports :

1. Erosion upstream of Farakka in Ganga
2. Erosion/Sedimentation of Himalayan rivers
3. Siltation – a natural process

Dr.Shitole stated that siltation is a natural process which effects the morphological changes of a river. Of late, several run of river schemes have been considered and planned in view of sufficient head available in Himalayan rivers for generating hydro power, irrigation, etc. There are lot of silt in Himalayan rivers which is deposited in reservoir thereby decreasing storage capacity. He stressed upon the importance of reservoir operation which can play an important role towards moderating natural flood. A study of Ukai reservoir vis-à-vis natural flood revealed that the flood could have been of less impact, had the reservoir been operated judiciously. CWPRS has conducted a study on river Ganga from Buxar to Mokama and has identified vulnerable reaches. In fact, the entire river from Buxar to Farakka was covered under this study. Dr. Shitole, CWPRS stressed upon water shed management and catchment area treatment for arresting sediment in a river instead of dredging which is very costly affair. Data collection on sediment is very important in order to fully understand the problem arising out of silt problem. CWPRS has developed models of rivers namely Kosi, Gandak, Ganga, etc. He emphasized that the river training works play an important role in the overall behaviour of a river. He also stated that raising of embankment height is not a viable solution to the problem. Chairman requested Dr. Shitole to send reports on silting of rivers, available with him to the Secretariat by post. He also wanted to know the experience of dredging from Buxar to Mokama. Dr. Bhatia informed the Committee that WAPCOS has prepared a morphological report on river Brahmaputra which can be referred while preparing the report. He desired that a note to be prepared on the network of stations meant for silt data collection by Central Water Commission and other agencies. It was felt that the critical reaches of rivers which are subjected to silting and causing problem thereafter need to be identified.

2.06 Shri A.K.Chakraborty from NRSA, Hyderabad suggested that the committee should address the following points :-

1. The genesis of problem
2. Magnitude of the problem
3. Measures to be taken –

   (a) Long terms such as Watershed Management, River Training Works, Raising of Embankments, etc.
   (b) Short terms such as Dredging of affected reaches of rivers.

He informed the committee that dredging may be resorted where it is economically viable as in case of Srisailam project. He suggested to distribute the work of the committee to different members. Dr. Bhatia suggested to include the basic process of silting and measurement techniques – economic as well as legal aspects. Shri Chakraborty informed that reservoir sedimentation is being estimated with the help of remote sensing data.

2.07 Shri B.C.Nayak suggested to find out long term solutions of the problem. He suggested to identify vulnerable reaches and remove extra silt from that particular area. As per Shri Nayak, Government of Orissa is not able to control silting of rivers in the state of Orissa in view of financial crunch. He informed that the Government of Andhra Pradesh has carried out some dredging operation in the Godavari delta which may be useful for the committee to prepare the report. In Orissa, near Paradeep, dredging was carried out to remove extra silt which was filled subsequently. There are some non-perennial rivers from which extra silt can be removed during dry season.

2.08 Prof. Sivasami from JNU shared his knowledge with committee regarding flood problem in Hiho river in China which experienced severe flooding in 1963. Consequent to this severe flooding in 1963, Government formulated a 10 year plan to get rid of flood menace. Huge amount of money was spent and thousands of people were engaged. In this river, a comprehensive approach was adopted to find the solution.

He suggested that the cost of dredging both by manually and mechanically needs to be worked out. There is silting problem at confluence of the river with sea as well as in embanked reaches. The vulnerable reaches need to be located and reason found out before recommending any solution. The implications due to involvement of catchments in foreign countries like Nepal, China should also be considered.

2.09 Shri Suresh Chopra, GSI stated that silting is a natural process and it cannot be stopped by artificial means. Nevertheless, the root cause of silting should be found out, taking the entire basin as a unit. He stated that siltation is a complex problem. There should be an action plan for controlling soil erosion. Proper study needs to be done to ascertain the cost of dredging and catchment treament. In his view, the cost of construction of small check dam to arrest the silt is much cheaper than that of dredging of rivers. He expressed that geology, lithology, morphology, seismic effects lead to sediment generation in a catchment. All these need to be studied to assess the sediment generation for recommending catchment area treament . GSI has prepared geo-morphological map of India which may be useful for the committee. GSI representative was requested to send a geo-morphological report to the Member Secretary for reference to the Committee.

2.10 The representative from Government of Bihar did not support dredging as a viable solution to tackle flood problem. As per his views, the rivers coming from across the border should be dammed to reduce silt load and simultaneously control flood in North Bihar plains.

2.11 Prof. Sivasami from JNU stated that silting cannot be stopped altogether and programme for maintenance of river regime be taken up. Community participation for removing silt is also necessary. Shri A.K.Chakraboary from NRSA, Hyderabad cited the example of Srisailam reservoir where dredging has been carried out to restore the storage capacity of the reservoir. He was, therefore, of the opinion that dredging should not be ruled out completely but should be thought of whether it is technically and economically viable. Capt. Rao from Vishakhapatnam suggested to provide safety to low lying area by bunds. He informed the committee that cost of dredging of river is in between 60 to 100 rupees per cubic meter. The Inland Waterways Authority has got dredging done at the rate of 43 rupees per cubic meter. In the meeting, it was decided to prepare a status on silt load data in Indian rivers. Shri Suresh Chopra, from GSI drew the attention of the committee to landslides in hilly area, resulting thereof heavy silt load in rivers.

3.0 DISCUSSION ON THE BRIEF OUTLINE OF THE DRAFT REPORT

3.01 The committee discussed on the outline of the draft report. It was decided that a Core group may be set up for finalisation of the draft report, based on the discussions and also on the different reports and papers received/collected from different sources. After deliberations, a Core Group consisting of the following officials was constituted with the consent of the Committee members :

1. Shri B.C.Nayak, Former Engineer in Chief, Irrigation Deptt., Govt. of Orissa

2. Prof. Sivasami, JNU
3. Shri K.K.S.Bhatia, Sc.F. NIH, Roorkee
4. Shri Suresh Chopra, Director, DPR Cell, GSI
5. Mr. G.Thakur, Director, CWC as Member Secretary

3.02 The members expressed the view that the report should be prepared in different chapters and the chapters should be written by different members which can be discussed in the next meeting of the Committee. The members then deliberated on the contents of the report and decided that the report will have about nine chapters. The Chairman requested all the members to volunteer their services in writing these chapters.

The details of the chapters and names of the authors which were finalized during discussions are as follows

1.	Definition of problem	-	Dr. K.K.S.Bhatia, NIH, Roorkee
2.	Review of literature	-	Dr. K.S.Sivasamy, JNU, Delhi
3.	Process of Sedimentation and Siltation	-	Dr. M.S. Shittole, CWPRS, Pune
4	Quantification and Identification of vulnerable reaches	-	Shri S.Chopra, GSI, New Delhi
5.	Remedial Measures their Merit economic, legal, environmentalAnd social aspects	-	Capt. M.V.Rao, Dredging Corporation of India
6.	Special problems	-	Shri A.K.Chakravarty, NRSA Hyderabad
7.	Case histories from India and abroad	-	Dr. K.S.Sivasamy, JNU, Delhi
8.	R&D in this field and future directions	-	Dr. K.K.S.Bhatia, NIH, Roorkee
9.	Recommendations and implementation of the recommendations	-	Whole Committee

4.0 ANY OTHER ITEM.

The members discussed on the issue of time by which the report is to be finalized. The Committee opined that a minimum 6(six) months time will be required to finalise the report as the original time allotted to the Committee will be ending on 07.04.2002. It was decided that Ministry of Water Resources will be approached for the extension of six months beyond 07.04.2002.

The meeting ended with a vote of thanks to the Chair.

LIST OF PARTICIPENTS WHO ATTENDED THE SECOND MEETING OF THE COMMITTEE ON 05.04.2002

1.	Dr B.K.Mittal, Ex Chairman, CWC	Chairman
2.	Sh. Tapas K.Sinha, SE, WRD, Bihar (representing Commissioner & Secy., Govt. of Bihar	Member
3.	Sh. M.V.Rao, Jt. GM, DCI	Member
4.	Prof. K.S.Sivasami, Professor, JNU	Member
5.	Sh. A.K.Chakraborty, Group Head(WR), NRSA	Member
6.	Sh. A.R.Ghatak, Hydrographic Chief, IWAI	Member
7.	Shri Suresh Chopra, Director, GSI	Member
8.	Dr. M.S.Shitole, Jt.Director, CW&PRSS	Member
9.	Sh. B.C.Nayak, Former Engg.- In- Chief, Govt. of Orissa	Member
10.	Dr. K.K.S. Bhatia, Sc.'F', NIH, Roorkee	Member
11.	Sh. S.K.Sengupta, Chief Engineer, P&D Orgn., CWC	Member Secy.
12.	Sh. Gorakh Thakur, Director, Morphology Dte. CWC	Sp. Invitee

RIVER SEDIMENTATION – PART II

In the last 50 years or so, several schemes including ones that related to flood mitigation/moderation were carried out with insufficient knowledge/experience of consequential effects. Out of exigency, several schemes have been undertaken which do not conform to the norms laid down by experts. It is felt that a thorough review be made in retrospect to gain knowledge on status of prevailing situation and also with a view to taking remedial measures. Natural and man made factors both are responsible for producing silt in a catchment of a river, flowing with rain water into a river. The science of silt flow is complex but the effect is conspicuous. The Brahmaputra river in the North-East furnishes a notable example, where the bed rose substantially since the severe earthquake of 1950. The low water level rose by as much as 3.4 m during 1947 to 1951. Man made factors include deforestation, large scale road construction, mining and cultivation on steep slopes.

II) Sediment load in rivers

The flowing water carries with it sediment depending on flow and channel characteristics. In ideal condition, a river should possess an amount of silt load which is just sufficient to make the river flow in a non-silting as well as non-depositing condition. This type of the river is characterized by the stability of the alignment of the channel and slopes as well as of its regime. The changes in bed and water slopes, etc. are insignificant over a long period. Such a river is known as stable channel. The second type is of degrading nature in which lowering of river bed is found. Such a river contains less than the silt load it can carry. The third category is known as aggrading type in which the river bed is raised due to silting phenomenon. A river may not be categorized as aggrading or degrading for its entire reach during the period as its nature changes along the reach and with respect to time. A study on river Kosi by Shri Sanyal, Chairman, GFCC showed that out of 6 reaches, only 4 were of aggrading nature. The rest i.e. two were of degrading nature. A similar study by Dr. D.C. Goswami on Brahmaputra indicated aggrading and degrading nature of the river. External interference affects the river behaviour. The Colorado river, for instance, below the Boulder Dam has become a degrading type after the construction of the dam. Aggradation is reportedly caused due to embankment in a river system.

Size of sediment is one of the most important and commonly used properties. Because of extreme irregularity in shape of the particle, size is usually defined by its volume, fall velocity, sieve size or tri-axial size. Sediment is called coarse, medium or fine depending upon its size. The composition of sediments varies from river to river depending on the physiographic set up of the basin. Sediments work as impediments in the development of Water Resources projects – flood control, irrigation and drainage, hydropower, navigation, fishery, etc. In 1984 the International Research and Training Centre on Erosion and Sedimentation was set up in Beijing. This center has pursued since then several research projects on siltation. As per Central Water Commission, the coarse, medium and fine particles are greater than 0.2 mm between 0.2 to 0.075 m and less than 0.075 mm respectively.

II) Some special features of Indian Rivers

Based on the physiography, the river systems of India can be classified into four groups, viz. (i) Himalayan rivers, (ii) Deccan rivers, (iii) Coastal rivers, and (iv) Rivers of the inland drainage basin. Himalayan rivers are perennial having large ratio of high and low flows. These rivers carry large volume of flood which is more than the carrying capacity of river. The upper reaches of the Himalayas are steep and fragile causing severe erosion and flowing with water. Majority of these rivers originate from across the Indian boarder. Himalayan rivers carrying high silt load and energy enter Indian plains of Ganga and Brahmaputra basins to unload its silt, simultaneously dissipating extra energy by eroding banks, bed, etc. The sediment then deposits and causes bed aggradation. When the bed is raised, the river shifts laterally. By this process, a cone shaped delta is formed by the river which presents the shape of a fan. Since this process is affected by silt brought down by river water, it is known as alluvial fan. The inland delta of river Kosi in Ganga basin is a well known example. A study by Mr. Gole and Mr. Chitale in 1966 on river Kosi revealed that the river has shifted 112 kms during the last 200 years. A brief description of river Kosi is noted below :-

The three major streams of the Kosi river are the Sun Kosi, the Arun and the Tamur which unite together at Tribeni. The river above Tribeni and for about 10 km downstream, flows in a deep gorge in the Himalayas until it debouches into the Gangetic plain at Chatra. The river slope in the gorge is about 2 m per km or steeper and the average annual sediment concentration at Barahkhetra in the gorge is 0.21 percent of the Sutlej at Bhakra Dam. The river slope after leaving the gorge progressively flattens from 0.2 m per km near Chatra town to 0.06 m per km at Kursela town where the Kosi joins the river Ganga. Average suspended sediment concentration at Kursela is only 24 per cent of that in the gorge. The remaining 76 per cent of the sediment load is deposited on the plain which has formed the alluvial fan of the Kosi extending, over 112 km eastwest and 160 km northsouth.

After deposits were formed where the river slope became deficient for carrying sediment further downstream, the adjoining part of the cone remained lower inviting the river to shift towards the low ground. When the flowing channels got silted up, the new side channels thus opened up and developed. The river by this process progressively shifted from one end of the fan to the other traversing a distance of 112 km from Purnea on the east to Nirmali on the west in a period of 200 years. The thickness of sand deposition after the Kosi has passed over the part of the cone was gauged to be about 2m.

Gandak is another important river of north Bihar, left bank tributary of Ganga and originating in Tibet. Out of 46300 km^2 of catchment, merely 7620

km^2 lies in India. The longitudinal slope at Balmikinagar is 5.7 m/km which gradually decreases to 0.17 m/km at Lalganj near Patna. As per one analysis, 95% of total sediment load comes during monsoon period. The upper reach of Gandak in India is frequently subjected to flooding, bank erosion, etc. The Gandak river in downstream portion is nearly stable. At Triveni, there has been degradation as per one study by CWC (Morphological Report, CWC, 34). At Dumarighat too, there has been net degradation. At Lalganj, there has however been aggradation. This result is subject to modification as the data is of short duration (5 years).

Brahmaputra river is another big river which comes from China with copious amount of flow and silt. The RL of origine is 3,600 m which descends to 150 at Sadiya in Assam. The slope of the river gradually decreases in the plains of Assam where its width increases. The width of Brahmaputra is around 16 km at Dibrugarh. The river carries enormous load of silt in its flow, thereby, degrading or aggrading its bed during the course. The river basin falls in active seismic zone (Zone V) and as such at periodic interval earthquake is experienced. These earthquakes bring about morphological changes depending upon intensity and the location of epicenter. The earthquake of 1950 in North East raised lower W.L. of Brahmaputra at Dibrugarh. As per one study, the lower water level of Brahmaputra rose by as much as 3.4 m, during 1947 to 1951 and thereafter remaining steady.

Silt Data Collection

Silt data collection is very important as silt load and its composition gives sufficient information about behaviour of the river. CWC has set up a big network for silt data collection on important rivers of the country. The silt samples collected are analysed to find out the constitutants of silt. Course (>0.2mm), medium (0.2mm to 0.075mm) and fine (<0.075mm). The Member (RM) of Central Water Commission is final authority for these data. The list of silt laboratories set up by CWC has been enclosed.

Definition of Problem :

River provides water for drinking, irrigation etc. The adjoining plain land is suitable for growing crops. The river basin has, therefore, attracted mankind since early times. In Ganga basin for example, there is high density of population. Till recently river was not subjected to manmade inference. The river would flow in its natural form. Changes in river morphology, hydrology, etc. would be guided by natural phenomena. In due course, there has been human interference whereby river is expected to behave in a particular way. The consequential effects of artificial interference are not known before hand. As a result, when one problem is tackled, another one crops up insidiously. In North Bihar, for example, extensive network of embankment has caused waterlogging and salinity problem, mainly on account of disruption of natural drainage system. At some locations in the plains of Bihar, embankment is not being considered useful. The river basin has its own hydrodynamic balance. By artificial interference, this balance is disturbed which affects channel geometry. The Secretary, Floods and Drainage, Govt. of Assam has advocated to ensure the land use pattern in a basin. Extensive cultivation, construction activities have caused erosion in upper land, therefore, enhancing silt load. In many cases, even natural phenomenon is being construed as menace. The siltation at the interface of river and sea is quite natural which results land formation gradually. The rate of land formation is shown below:

Name of River	..	..	**Extension of delta per century**
Irrawaddy	..	..	3 miles
Mekong	..	..	3 miles
Red River	..	..	3.5 miles
Mississippi	..	..	4 miles
Po	..	..	3 miles
Mahanadi	..	..	2.5 miles

1 miles = 1.609 km

As the river flows through erodible surface, it carries silt. In fact, alluvial plains have been formed by the silt carried down by river water. Rate of silting of rivers is said to have increased. No thorough study has so far been made in this regard. This is said to have caused rise of flood level. As per CBIP report, flood level of Brahmaputra at Dibrugarh has been increasing gradually. But the possible reason has not been traced out conclusively. These consequences are attributed to embankment which prevents the river from spreading flood water on either side. It is to be noted that embankment is resorted to throughout the world as an effective flood control measures. The river behaviour vis-à-vis embankment has to be understood in general and at problematic areas in particular.

Remedial Measures :

The remedial measures have to be taken to get rid of the problem or at best to lessen the problem. The problem is complex and naturally it has to be confronted from every possible angle. Every river is a separate hydrological entity with special physiographic set up and characteristics. The Secretary, Flood and Drainage, Govt. of Assam has attributed earthquake as reason to bring about changes in channel geometry thereby disturbing hydrodynamic balance. There can be hardly any solution to a problem caused by such a phenomenon. Faulty agricultural practice, developmental activities in the upper reach have been mentioned to have exacerbated the silt load in Brahmaputra. He has suggested to carry out watershed management and ensure land use pattern as per national policy. 33 1/3% forest, 33 ½ % horticulture and 33 1/3 agricultural practice. The Secretary has ruled out dredging as possible remedial measure. He has however suggested to try dredging operation in a tributary where velocity is low. DVC has carried out reservoir survey which has indicated silting of reservoir and reduction in storage capacity therefrom. Watershed management has been initiated by DVC authorities to reduce silt entry into the reservoir. Watershed management pursued by DVC consist in afforestation and silt control structures.

In Orissa, tidal rivers are also subjected to siltation at their mouths. This cuses overtopping of banks. Shri B.C.Nayak, former Engineer-in-Chief, Govt. of Orissa has suggested for raising of embankment height, conforming to the higher level of water due to bed rise. He has recommended for removing the extra silt manually, mechanically or by dredging in vulnerable reaches. The silt thus removed has been suggested to be utilized for construction purposes.

Shri Rajiv Sinha, et el from I.I.T. Kanpur in their article "Flood Hazards of North Bihar Rivers, Indo-Gangetic Plains" have called dredging operation technically unsound which will involve phenomenal costs. They have suggested for hydro-meteorological, geomorphological and silt studies. They have advocated management of catchment conditions with the help of afforestation and soil conservation practices. Prof. K.S.Siva Swami from JNU, New Delhi has suggested for a critical appraisal of flood control schemes namely embankment, reservoir, etc. He has advocated for pursuing pragmatic approach while developing water resources of the country, giving due considerations to environmental aspects.

In the light of the above discussion, the suggested measures may be encapsulated as below :-

1. Data collection for carrying out hydrometeorological, geomorphological and silt studies should be ensured.
2. Vulnerable reaches in respect of silt should be identified.
3. Remedial measures should be location specific.
4. Watershed management/catchment area treatment should be undertaken to reduce silt entry.
5. Dredging in general should be avoided. It may, however, be undertaken in selective reaches subject to economic viability.

Possible Alternatives to solve the problem

The problem of silt cannot be seen in isolation. The solution would not be found out isolation as well. In fact, silting is a part of river behaviour. The extent and nature of silting has to be ascertained conclusively in the first place. A few studies on silting do suggest aggradation trend. Overtopping of embankment does not necessarily indicate silting in a river bed. Even reduction of carrying capacity of Damodar river has gone down after construction of dams at Maithon and Panchat. As the flood flow has been moderated following operation of dam, the discharging capacity has gradually decreased. Controlled flooding has been done in some rivers in U.S.A. The embankments in India have been designed for 25 years return period in rural area and for 100 years in urban area. India cannot afford to design embankment for probable maximum flood. Economy does not allow it. So, overtopping cannot be ruled out.

River that enter into Indian territory from across the border are not easily accessible to Indian experts and official. This adds a new dimension to the problem of watershed management. Brahmaputra river, for example, has half its catchment in China. Major rivers of Bihar originate in Nepal or China. The catchment portion in India may however is managed easily.

Tidal rivers of Orissa and West Bengal are reported deposit silt where they fall into sea. The mouths are to checked to ensure water flow without affecting embankment. The scheme of dredging in the basin of Icchamati in West Bengal could not succeed as suitable location of silt disposal was not available. The scheme for a tidal river should be prepared as per specific problem. Shri B.C.Nayak has suggested for model study. The model study may be useful. An experiment on prototype model may also help to find out the efficacy of dredging operation. Government of Assam had untaken dredging operation mid-seventies in Brahmaputra, the result of which was not encouraging. The Government of Assam forsook the plan of dredging operation thereafter as the dredged portion was filled up in the next season. The authorities have reported it to be costly proposition.

Conclusion:

The consequences of silting in embanked rivers are yet to fully qualified. The morphological changes brought about by embankments need thorough study before remedial measures are considered. In china, for the last 4200 years, efforts are on for taming the yellow rivers, one aspect of their program is silt control. There is severe silting in the lower reaches of Yellow river. The embankment height has been raised to account for gradual aggradation of river bed. Simultaneously other measures like silt management, waters bed management, construction of reservoir, etc are have been undertaken. The present situation on silting of river bed is in incipient store which would gradually aqqravate, if not palliative measures taken. It would be appropriate to embank upon specific study on each problematic river giving due considerations to vulnerable reaches. Pending this study some ad-hoc measures like bridging, rising of embankment height may be done taking into considerations local and consequential factors.

No. 3/25/2001-Morpho/442-457
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 11.6.2002

Sub:- Third Meeting of the Committee to study the Problem of Silting in Indian rivers.

Third meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 04.07.2002 at 11.00 hrs. in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. All the members are requested to kindly make it convenient to attend the meeting. The members are also requested to kindly submit any article/material relevant in this regard to Member Secretary at the earliest.

The agenda of the meeting is noted below :-

1. To confirm the minutes of the 2nd meeting held on 05.04.2002.
2. Report by Member Secretary on the status of the work progress of the Committee.
3. Review of the progress of writing draft chapters.
4. Review of Draft Chapters received from members.
5. Any other item with the permission of the Chair.

Authors are requested to kindly send the draft chapters assigned to them by the Committee in the second meeting held on 05.04.2002 to the undersigned latest by 24.6.2002.

Members are requested to kindly intimate their programme to the Member Secretary.

Thanking you,

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

MINUTES OF THE THIRD MEETING OF THE COMMITTEE TO STUDY THE PROBLEM OF SILTING IN INDIAN RIVERS HELD ON 4TH JULY, 2002 IN THE COMMITTEE.0E ROOM OF THE MEMBER(RM), CWC, SEWA BHAWAN, R.K.PURAM, NEW DELHI - 110066

The Chairman of the Committee on Silting in Indian rivers, Dr. B.K.Mittal welcomed the members and thanked them for attending the meeting. Name of the participants is enclosed as Annexure-I.

The Chairman in the very beginning mentioned the letter written by Mrs. Radha Singh, Additional Secretary, MOWR for completing the Committee's work by 6th August, 2002. In this connection, it was mentioned by the Chairman that as per present schedule, the tenure of committee will expire on 6th August, 2002 as only 4 months extension had been granted by MOWR. Members opined that it may not be possible to finalize the report of such magnitude within this period which requires a study of technical literature and research studies available on the subject by the 6th August 2002 and further extension may be requested from MOWR. After deliberations on the issue, it was decided that the MOWR should again be requested to extend the tenure of the committee by 2 months as originally sought for after the next meeting. The Chairman then asked the Member Secretary to carry on further.

1.0 CONFIRMATION OF MINUTES

The Member Secretary thereafter, requested the members to confirm the minutes of the second meeting. Mr. B.C.Nayak requested the members to refer Para 2.07 of the minutes of the 2nd meeting wherein it is mentioned " In Orissa , near Paradeep , dredging was carried out to remove extra silt which was filled subsequently". He clarified that he did not mention that it was filled subsequently but stated that it may get filled up subsequently. The Committee took note on it and decided to modify the same accordingly.

The committee approved the minutes of the 2nd meeting incorporating modification suggested by Shri B.C. Nayak.

2.0 PROGRESS OF THE STUDIES CARRIED OUT AND REVIEW OF THE MATERIAL RECEIVED FROM MEMBERS

2.01 The Member Secretary apprised the members of the status of work since the second meeting. The meeting of the core group was held on the 21st May, 2002 in which Prof. Sivasami, Dr. K.K.S.Bhatia, Shri B.C.Nayak, Shri Suresh Chopra and Shri G.Thakur participated to review the progress of the chapters to be written by Members. The Member Secretary informed the committee on the status of the report.

2.02 Members wanted to know about the contents of the report to be finalized by the committee. Dr. A.K.Chakraborty suggested that the report should be as precise as possible since bulky report is generally not read. The Chairman intervened and informed the committee that the report should be fully informative with the executive summary containing all the salient feature of the Report. The Chairman, GFCC suggested that it should be a technical report containing all the aspects in a comprehensive way for future reference and the Executive Summary so prepared to take care of the points relevant on the issue.

2.03 Efficacy of Dredging Operation

The Chairman requested Shri A.R.Ghatak from IWAI to write a note on dredging carried out by his organization which would be included in the report. He agreed to prepare the note. Prof. Sivasami, JNU informed the committee that in 1970's, dredging was carried out in Assam, the performance of which should be included in the final report. He informed that dredging is generally carried out in estuary reaches or for some specific purpose like navigation, etc. In his opinion, river dredging is the last resort. Chairman, Dr. B.K.Mittal referred to the Keskar Committee Report which recommended dredging at Farakka Barrage Project. Chairman, GFCC informed the Committee about the model study conducted by CWPRS, Pune on river Ganga at Farakka. The Chairman, GFCC informed the committee that no dredging at Farakka Barrage Project was actually carried out. The Chairman, Brahmaputra Board wanted that the Committee should study the rivers in Brahmaputra Basin also.

2.04 Status of Different Chapters

The Member Secretary informed that the members were requested to complete the chapters by the 30th June, 2002, but no chapter till date has been received in complete form. However, Shri Suresh Chopra, GSI presented the draft chapter in the meeting which was circulated to members. Prof. Sivasami informed the members that he has collected material on the rivers in China and other foreign countries for the chapters assigned to him. He then requested members to provide him materials pertaining to India. The Chairman, Dr. B.K.Mittal suggested Prof Sivasami to refer CBI&P Publication, Keskar Committee Report and Pritam Singh Committee Report. The Chairman in this context requested Shri S.K.Das, Chairman, GFCC to look for these reports in GFCC and pass on the same to the Member Secretary for reference. He assured the Chairman to do the needful in this regard. The Chairman, GFCC was requested to send the report on silting of Kosi river also.

2.05 Dredging Carried out by IWAI

Shri A.R.Ghatak informed the members that the dredging conducted by IWAI is localized and generally done in a width of 45 metres and one km length. In such a dredging operation , the dredged material is disposed in the river itself.

The Chairman, requested Shri Ghatak to prepare a report highlighting the fact that dredging does not lead to permanent solution.

2.06 The Commissioner-cum-Secretary, MOWR Bihar Government informed the committee that rivers in Bihar especially those in Adhwara group of rivers are reporting rise of their bed alarmingly. He attributed massive deforestation in the upper catchment of these rivers. Dredging was not considered to be a solution in this regard.

2.07 Shri A.K.Chakraborty, NRSA informed about their study carried out on river Ganga for the reach from Buxar to Farakka in which bankline changes have been shown with the help of remote sensing data. It was also reported that severe erosion downstream bridge near Buxar has been occurring for long period. Some engineers think that constriction caused by construction of bridge may be the cause. Member (RM) suggested for the measures to minimize the silt load in a river. There was discussion about the feasibility of dredging operation in order to increase the carrying capacity of river in flood prone area.

3.0 EXTENSION OF THE TENURE OF THE COMMITTEE

The Member Secretary informed the committee that six months extension was sought from MOWR but only four months extension has been given according to which the tenure of the committee will end on 6th August, 2002. Further extension was thought necessary by the committee and Shri Chakraborty suggested for submitting an interim report of the committee. The Member(RM) said that in view of the nature of work, interim report might not be possible. All the members suggested for approaching MOWR for granting extension for two more months.

4.0 DISCUSSION ON THE CONTENTS OF THE REPORT

Chairman, GFCC suggested that all the authors may be requested to expedite the writing of the chapters , assigned to them. Thereafter, the Chairman reviewed the status of finalisation of different chapters, decided in the last meeting from the authors concerned. It was decided by the Chairman that river sedimentation data pertaining to Kosi, Gandak, Ganga, Brahmaputra, Mahanadi, Subansiri be obtained from State Governments to include the same in the final report. Shri B.C.Nayak mentioned that erosion and siltation go on simultaneously in a river basin. He mentioned about the work, given to IIT Madras on river siltation in some rivers of Orissa in which IIT Madras has suggested for removing silt from river bed. Shri Suresh Chopra from GSI attributed silt load in a river due to pressure on land and encroachment of flood plains of a river basin. Shri A.K.Chakraborty informed the committee about the facts in which dredging has been recommended as a special case in Srisailam reservoir. The Member Secretary requested Shri Chakraborty to send a report of the same to him. The Chairman requested Mr. Chakraborty to include in his chapter Butinidiara, the Majuli island etc. The Chairman wanted some special study on Bihar particularly North Bihar where flooding is extremely acute.

5.0 ANY OTHER ITEM

5.1 The Chairman, GFCC was requested to write a chapter on river Ganga on the distinct behaviour of the river. He consented to complete it before the next meeting.

5.2 Prof. Sivasami mentioned about the flood problem of river Yellow in China. Member (RM) explained the flood problem in rivers of DVC system and the flood carrying capacity of rivers.

5.3 It was decided that the 4th meeting of the Committee may be held on 1st August 2002 at New Delhi to finalize the draft chapters.

5.4 The meeting ended with a vote of thanks to the Chair.

LIST OF PARTICIPENTS WHO ATTENDED THE THIRD MEETING OF THE COMMITTEE ON 04.07.2002

1. Dr B.K.Mittal, Ex Chairman, CWC	Chairman
2. Sh.S.K.Das, Member(RM), CWC	Member
3. Sh. S.K.Das, Chairman, GFCC, Patna	Member
4. Sh. K.D.Saharia, Chairman, Brahmaputra Board	Member
5 Sh. V.Jayashankar, Comm. & Secy.,WR Deptt, Govt. of Bihar	Member
6. Prof. K.S.Sivasami, Professor, JNU	Member
7. Sh. A.K.Chakraborty, Group Head(WR), NRSA	Member
8 Sh. A.R.Ghatak, Hydrographic Chief, IWAI	Member
9. Shri Suresh Chopra, Director, GSI	Member
10. Sh. B.C.Nayak, Former Engg.- In- Chief, Govt. of Orissa	Member
11. Sh. T.K. Sinha, SE, Pl.& Mon., WR Deptt, Sinchai Bhawan, Patna	Member
12. Sh. S.K.Sengupta, Chief Engineer, P&D Orgn., CWC	Member Secy.
13. Sh. Gorakh Thakur, Director, Morphology Dte. CWC	Sp. Invitee

No. 3/25/2001-Morpho/534-550
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 12.07.2002

Sub:- Fourth Meeting of the Committee to study the Problem of Silting in Indian rivers.

Fourth meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 01.08.2002 at 11.00 hrs. in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. All the members are requested to kindly make it convenient to attend the meeting.

The agenda of the meeting is noted below :-

1. To confirm the minutes of the 3rd meeting held on 04.07.2002.
2. Report by Member Secretary on the status of the work progress of the Committee.
3. Discussion on the draft report of the Committee.
4. Discussion on the final chapter to be authored jointly.
5. Any other item with the permission of the Chair.

Authors are requested to kjindly send the draft chapters assigned to them by the Committee by 23rd July, 2002 to enable us to compile the same and circulate to all the members in advance for fruitful discussion in the meeting.

Members are requested to kindly intimate their programme to the Member Secretary.

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

MINUTES OF THE FOURTH MEETING OF THE COMMITTEE ON SILTING OF RIVERS IN INDIA

The Chairman of the Committee Dr. B.K.Mittal welcomed the members of the Committee. Names of the members who attended the meeting are enclosed as Annexure-I. The Chairman, thereafter, requested the Member Secretary to brief the Committee about the works that have been done since the third meeting was held.

1.0 CONFIRMATION OF MINUTES OF 3RD MEETING

1.01 The Member Secretary invited the attention of the members to the Minutes of the third meeting which were circulated to members. Comments from IWAI on efficacy of dredging operation (Para 2.03 of the minutes) were presented to Committee. IWAI has requested in its communication for replacing the sentence "river dredging is the last resort" with "for alluvial rivers like Ganga and Brahmaputra, siltation would be effected subsequent to each monsoon for which some kind of river conservancy works like dredging/Bandalling needs to be done for maintaining the minimum navigational depth. As long as the river is not stabilized with permanent river training measures, dredging need to be carried out for maintenance of channel for navigation". The Member Secretary desired to know the view of the members on modifying the minutes as requested by IWAI.

Shri Shitole from CWPRS, Pune informed the committee that dredging may be necessary for navigation purpose normally. Shri B.C.Nayak also participated in the discussion and expressed his opinion. Member (RM) stated that it is a known fact that dredging is necessary for navigation purposes but the dredging in the minutes has been used in a different context. Chairman suggested that the minutes may be modified by adding the sentence "Selective dredging may be carried out locally for navigation" which was agreed by all the members.

1.02 The Member Secretary mentioned about the second part of the modification suggested by IWAI wherein the sentence "no dredging at Farakka Barrage Project was actually carried out" to be replaced with "IWAI has carried out dredging at Farakka, the details are as follows :-

1999-2000	-	1.1 lakh cu.m.
2000-01	-	0.2 lakh cu.m.
2001-02	-	1.0 lakh cu.m.
Total	-	2.3 lakh cu.m.

On deliberation on the issue the Chairman informed that dredging was indeed recommended by Keskar Committee at Farakka. The Member Secretary informed the Committee that the aforesaid statement (no dredging at Farakka

Barrage Project was actually carried out) was made by the Chairman of GFCC, Patna. Shri S.K.Sinha, Member, GFCC reiterated that the Farakka Barrage Authority has acutally not carried out any dredging operation. It was decided that there is no need of modifying the minutes on this issue.

1.03 The Member Secretary mentioned the third part of the modification/addition that has been suggested by IWAI in the minutes of the 3rd meeting. The Chairman, Dr. B.K.Mittal informed the committee that a committee under his Chairmanship was constituted by Government of India which recommended mathematical model study to be carried out by CWPRS. He asked the representative from IWAI to send a note on it to append in the report. Participating in the discussion, Shri A.K.Chakraborty suggested that it should not be written that dredging is not a solution.

The Member Secretary in this context mentioned about the report submitted by Government of Assam which was circulated to members. The Member (RM) explained the natural process of river behaviour in which rising and lowering of bed takes place during different stages of river. He stated that as all the comments indicated by IWAI were related to dredging of channels for navigation point of view, it may not be appropriate to modify the minutes by incorporating the same. All these facts can be included in the report as annexure. The members agreed on the observations made by Member(RM).

Shri A.K.Chakraborty explained about the dredging operation that has been carried out in Krishna river downstream of Srisailam dam. He requested to correct the minutes and replace the sentence "Srisailam reservoir" with "The Krishna river reach downstream of Srisailam dam". Prof. Sivasami wanted to include some sort of quantification of silting in rivers on the basis of the data provided by IWAI in their letter. The Member (RM) elucidated the points raised by Prof. Sivasami. Shri B.C.Nayak mentioned that in one river of Orissa scouring has been occurring since last 30 years in one bank of the river whereas in the other bank silting has been taking place. He informed the committee that IIT, Madras following its study of river behaviour has suggested for dredging operation in one side of the river. He stated that dredging cannot be avoided altogether. The Member (RM) intervening in the discussion stated that dredging may not help to increase the carrying capacity of a river. He cited example of West Bengal where dredging could not be carried out due to non availability of suitable site for disposal of dredged material. Durgapur Barrage has undergone reduction in its design capacity because of silting.

1.04 The Committee approved the minutes of the 3rd meeting issued by incorporating the modifications discussed above.

2.0 STATUS OF THE WORK/PROGRESS OF THE STUDIES CARRIED OUT BY THE COMMITTEE

2.01 The Member Secretary briefed the committee on the status of the draft report vis-à-vis progress since the holding of the third meeting. He informed the committee that the draft chapters from Mr. Chopra of GSI. Mr. Shitole of CWPRS, Mr. Chakraborty of NRSA and Prof. Sivasami of JNU had been received by him. The two chapters from Mr. K.K.S. Bhatia of NIH and one chapter from Mr. Rao of Dredging Corporation of India, Vishakhapatnam are still awaited. Besides, the Chairman, Brahmaputra Board has forwarded a write up on "Siltation in River Brahmaputra" and Secretary, Govt. of Assam has forwarded a report on the matter of Desiltation of river Brahmaputra. Prof. Sivasami, JNU mentioned about the progress of the chapters authored by him. He also mentioned about the condition of Hiho river in China. The Chairman Dr. B.K.Mittal enquired about the problem of Tigress and Eupharates rivers from Prof. Sivasami. The Member (RM) wanted to know about the performance of dredging operation carried out by IWAI. The representative from IWAI was requested to furnish a write up on dredging operation that had been carried out by them. Shri A.K.Chakraborty was also requested to send a report on dredging operation that has been carried out in Krishna river. The Chairman asked the members to volunteer themselves to go through the draft report. Dr. Shitole from CWPRS informed the committee that Prof. Garde has agreed to go through the report of the committee. On the suggestion of the Chairman to form a core group to edit the different draft chapters before putting up to the members for acceptance, it was decided that the Core Group which is already in existence should take up these activities. The Chairman asked the Member Secretary to prepare a dummy report in proper format leaving blank space for the chapters not yet received giving page number chapterwise. The Chairman also desired that the dummy report thus prepared should be circulated to members of the Core Group with a copy to him for their views. Once the draft report is ready the same can be forwarded to Mr. Garde and Mr. Bharat Singh for their comments/suggestions.

2.02 Terms of Reference

Shri A.K.Chakraborty from NRSA, Hyderabad drew the attention of the members on terms of reference of the committee. He also stated that IWAI and CWPRS were competent to comment upon the appropriateness/ technical feasibility of methods employed for desilting of rivers. Shri A.K.Chakraborty suggested that some direction to tackle the problem of siltation be recommended in the report, keeping in view the terms of reference of the committee. Prof. Sivasami suggested for tuning the report in accordance with terms of reference. The Member Secretary mentioned in this context that the dredging operation carried out by IWAI was inevitable to ensure navigability of boats and ships. But in order to alleviate flood menace, dredging operation may not be normally conducive on account of several practical problems. IWAI has been reported to have carried out dredging operation upstream of Farakka Barrage but it has been exclusively for navigation purpose. Dr. Shitole from CWPRS, Pune informed the committee that CWPRS has not carried out any study on dredging of rivers so far.

2.03 Model Study of river Ganga

Shri A.K. Chakraborty from NRSA, Hyderabad suggested to have model study of river Ganga from Allahabad to Farakka in order to ascertain the behaviour of the river. Dr. B.K.Mittal informed the members that model study by CWPRS, Pune in the entire reach i.e. Allahabad to Farakka may not be feasible due to various reasons. Moreover three dimensional model on such a big river is not practicable.

2.04 Measures to Reduce Silting

Prof. Sivasami wanted to know the efforts and results of catchment area treatment carried out by DVC to reduce siltation.

The Member (RM) informed the committee that DVC had not done any worth mentioning work which has reduced the silt load. The live capacity of Durgapur Barrage has been reduced by silting. DVC has not carried out any study to ascertain the effect of soil conservation measures taken so far on silt transportation/deposition. The Member (RM) mentioned about the Kosi river of Bihar in which enormous silting problem has been reported. The Member (RM) added in the context that at first the reason of desilting needs to be found out. He stated that the studies had already been conducted on problematic rivers like Kosi, Brahmaputra, etc. These studies do not indicate that silting has occurred all along the reaches. He suggested for morphological study be carried in totality before arriving at any conclusion.

3.0 ANY OTHER ITEM

3.01 Silt Data Flood Prone Rivers

Shri S.K.Sinha, Member, GFCC wanted silt data of Ganga, Brahmaputra, etc. to be included in the report in order to provide corroborative evidence vis-à-vis silting/non-silting of rivers. Dr. B.K.Mittal suggested to include the analysis of silt data without giving actual figures. The trend of silt load, according to the Chairman, can be reflected in the report without infringing the norms which have been laid down by MOWR in this regard. However, it was suggested by members to obtain written permission from MOWR to facilitate the committee for using the silt data.

3.02 Extending the Tenure of the Committee

The Member Secretary informed the committee that the tenure of the committee would end on 07.08.2002 following MOWR approval of 4 months' extension instead of 6 months which was originally sought by the Committee. Members wanted more time to finalise the report and as such the committee directed the Member Secretary to send a fresh letter to MOWR seeking two months extension to complete its work.

3.03 Structure and Sequence of Contents of the Report :

The Chairman asked the Committee to start preparing report in appropriate sequence. First of all he wanted to know the design of cover. In this regard he requested the members to provide photographs to the Member Secretary. He further asked to compile following documents for the report :-

i) Ground photographs
ii) Terms of reference
iii) List of members who attended meetings
iv) Copy of letters
v) Bibliography
vi) Letters of Transmittal
vii) Zero Chapter
viii) Executive Summary
ix) Recommendations in brief

3.04 The meeting ended with a vote of thanks to the Chair.

LIST OF PARTICIPENTS WHO ATTENDED THE FOURTH MEETING OF THE COMMITTEE ON 01.08.2002

1. Dr B.K.Mittal, Ex Chairman, CWC	Chairman
2. Sh. S.K.Das, Chairman, GFCC, Patna	Member
3. Sh. D.K. Shrivastava, Chief Engineer, Planning & Monitoring, WR Deptt., Sinchai Bhawan, Patna	Member
4. Prof. K.S.Sivasami, Professor, JNU	Member
5. Sh. A.K.Chakraborty, Group Head(WR), NRSA	Member
6. Sh. T.V. Prasad, AHS, IWAI, NOIDA	Member
7. Sh. M.S. Shitole, Jt. Director, CWPRS, Pune	Member
8. Sh. B.C.Nayak, Former Engg.- In- Chief, Govt. of Orissa	Member
9. Sh. S.K.Sengupta, Chief Engineer, P&D Orgn., CWC	Member Secy.
10. Sh. Gorakh Thakur, Director, Morphology Dte. CWC	Sp. Invitee

No. 3/25/2001-Morpho/771-87
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 23.9.2002

Sub:- Fifth Meeting of the Committee to study the Problem of Silting in Indian rivers.

Fifth meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 4.10.2002 at 11.00 hrs. in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. All the members are requested to kindly make it convenient to attend the meeting. The members may prepare article/material relevant in this regard and hand over the same to the Chairman of the Committee during the meeting.

The agenda of the meeting is noted below :-

1. To confirm the minutes of the fourth meeting held on 01.08.2002.
2. To review the progress regarding the preparation of the report.
3. To prepare theninth chapter containing recommendations/suggestions.
4. Any other item with the permission of the Chair.

Kindly confirm regarding participation in the fifth meeting.

Thanking you,

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

MINUTES OF THE FIFTH MEETING OF THE COMMITTEE TO STUDY THE PROBLEM OF SILTING IN INDIAN RIVERS HELD ON 4TH OCTOBER, 2002 IN THE COMMITTEE ROOM OF THE MEMBER(RM), CWC,Sewa Bhawan, R.K. Puram, New Delhi - 110066

The Chairman of the Committee Dr. B.K.Mittal welcomed all the members for attending the meeting. He informed the Committee that MOWR was expecting the work to be complete by the 6th October, 2002. He further added that the report has almost been ready except some portion. The chapters received from the members have already been circulated to the members of the Core Group. The Chairman further informed that he had gone through the report and had subsequently suggested some changes. The Chairman advised to prepare Master Copy consisting of all the chapters for further reference. He informed the committee that data are, not readily available because of which the progress on report preparation is at times sluggish. Thereafter, the Chairman asked the Member Secretary to inform the Committee about the activities since the 4th meeting.

1.0 CONFIRMATION OF MINUTES OF THE 4TH MEETING

The Member Secretary welcomed the new member to the Committee, Shri Gopal Krishnan, Member (RM) as it happened to be his first meeting.

2.0 The Member Secretary requested the members to confirm the minutes of the 4th meeting without any modification as no comment from any member was received. The members subsequently confirmed the minutes of the 4th meeting. The Member Secretary informed the committee that all chapters except the one, to be authored by Prof. Sivasami, have been received. He further added that one chapter by Dr. K.KS.Bhatia would need further addition/deletion. Thereafter, the Member Secretary requested Dr. K.K.S.Bhatia to apprise the members regarding the progress of the work with regard to the Core Group.

3.0 PROGRESS MADE BY CORE GROUP :

Dr. K.K.S.Bhatia informed the committee that so far three meetings of Core Group were held in which considerable progress was achieved. He mentioned following chapters. :-

i) Definition of the Problem

ii) Review of Literature

iii) Process of Sedimentation and Siltation

iv) Quantification and Identification of vulnerable reaches

v) Remedial Measures, their Merits, Economic, Legal, Environmental and Social Aspects.

vi) Special Problems

vii) Case history from India and abroad

viii) R&D in the field and future directions

ix) Recommendations and implementation of the recommendations.

3.01 Dr Bhatia informed the committee that draft chapters have been received. Relevant informations from Govt. of Assam and Orrisa, GFCC, Brahamputra Board etc. have been received and a chapter on these inputs has been drafted by the Core Group. He added that silt data and cross-sections pertaining to important sites of CWC are also to be included. He finally presented a brief review of chapters, received so far.

3.02 Reviewing the chapter-IV Dr. Bhatia suggested that inputs from State Governments be included in it. Shri A.K. Chakarborty from NRSA wanted that the report is edited in order to make it consistent and relevant to TORs. The Chairman intervening in the discussion, enquired on the chapter relating to research and development for which he requested members to send their comments so that the same could be included. In this context, he mentioned Keskar Committee and six task force Committees which were constituted to look into the flood problem of the country. He asked the Member Secretary to collect the reports prepared by these task force Committees from Commissioner (ER).

4.0 EFFICACY OF DREDGING

The Chairman, Dr. B.K.Mittal subscribed to the view that dredging is a temporary measure. Dr. K.K.S. Bhatia, while commenting upon the efficacy of dredging stated that enlarged cross-section by dredging does not last as such changes induce rapid as well as more siltation. Dr. B.K.Mittal said that for certain reaches dredging may be helpful till permanent arrangements are made in a river.Shri B.C.Nayak in this regard cited the example of Devi river, a major tributary of Mahanadi where enormous silting has taken place. Government of Orissa, according to him, had referred this problem to I.I.T., Chennai who have inter-alia recommended dredging operation in the river. Dr. B.K. Mittal cited another example of Ganga at Kanpur where morphological change in the river has been attempted through hydraulic structure and therefore, he suggested that the committee should keep itself open for dredging also.

4.01 Desilting of rivers

The Member(RM) suggested to identify problematic reaches and suggest specific solutions taking into consideration prevailing conditions in such reaches. He was of the opinion that dredging may be done in channels, if so required. Efficacy of dredging, according to him, in river channels in general has to be ascertained. Shri B.C.Nayak intervened in the discussion and suggested for dredging operation subject to local conditions. Prof. Sivasami from JNU said that desilting of rivers in channels becomes necessary in many cases. Dry sand may also be required to be removed, like the one that has been done in Tamil Nadu, Punjab etc. Such works already done in India, suggested Prof: Shivashami, ought to be included in the report.

4.02 Chairman, Dr. B.K.Mittal informed the committee that Don Canal in Nepal has been desilted manually by Government of India. Dr. K.K.S. Bhatia expressed that various methods of desilting have been covered in view of the terms of reference of the Committee. Dr. B.K.Mittal, Chairman informed that Indian rivers are very mighty and large and as such dredging may not be economically practicable in view of problem of disposal of dredged material. He informed that dredging is generally done for navigation but not for flood control.

4.03 The General Manager, Brahmaputra Board Shri Barkataki attributed the silting of Brahmaputra and its tributaries due to heavy silt load coming from hilly areas. He further stated that Brahmaputra in general is shifting towards south because of enormous silt from north bank tributaries. Dredging, he informed, has been tried in Brahmaputra earlier with doubtful result. He also agreed with the chairman that dredging is a temporary measure especially in a river like Brahmaputra which is swollen like a sea during monsoon period. He contended that the river Brahmaputra cannot be dredged and following measure are required.

i) Afforestation/ reforestation .

ii) Detention Reservoirs .

4.04 The General Manager referred in this context that Bhomragudi road bridge at Tezpur in Assam which has brought about Morphological changes manifesting shoal formation downstream of the bridge. He apprehended possible adverse consequences of the proposed bridge at Dibrugarh.

4.05 The Member (RM) requested Dr. Shitole from CWPRS Pune to make available the reports which they have prepared in connection with Morphological changes in flood prone rivers. Further, the General Manager, Brahmaputra Board mentioned the problem faced by Majuli Island whose north Bank as of now is getting silted up while that on the south is getting eroded gradually. The Member (RM) suggested that such vulnerable reaches be included in the report, and requested the members to furnish such informations to the Committee.

4.06 The General Manager, Brahmaputra Board mentioned Phulwaria where too, much silting is taking place. He informed the committee that due to faulty execution of schemes at south of Sulwaria, Dhubri is getting affected. The Member Secretary requested the General Manager, Brahmaputra Board to give such informations on vulnerable reaches in writing to the committee. Prof. Sivasami from JNU concurred with the member secretary and requested members to provide informations, etc. regarding vulnerable reaches.

4.07 Shri R.M. Nair from IWAI was of the opinion that desilting of rivers like Ganga, Brahmaputra etc is not practicable. However, non alluvial rivers like the ones in Orissa, etc. according to him, may be considered for desilting operation.

5.0 REVIEW OF LITERATURE

The Chairman requested Prof. Sivasami to include cases of desilting operations in respect of rivers in India and abroad in his chapter. Major rivers of India, said the Chairman, should particularly be considered. Shri B.C.Nayak offered his comments on Chapter-I which Dr. K.K.S. Bhatia agreed to consider.

5.01 Review of Chapter-III

Chapter-III, prepared by Shri Shitole, CWPRS, Pune was discussed by the Committee. The Chairman, Dr. B.K.Mittal expressed that the chapter is too academic to be appreciated by field engineers/other people and as such requested to make it slightly less mathematical. He also requested to include important references at the end of the chapter notwithstanding Bibliography to be added at the end of the report.

5.02 Review of Chapter-IV

Dr. B.K.Mittal requested for some addition in the chapter and Shri B.C.Nayak requested for river Baitarni to be included in it. It was also informed in the meeting that river Damodar joins river Hooghly. The discussion veered away from the 4th chapter and round to the master copy.

6.0 MASTER COPY

It was decided in the meeting that two copies of the draft report – one for MOWR and other for the committee would be prepared by the 30th Nov., 2002. Fiqures as per the discussion, will be marked chapterwise. Overlapping informations/materials may be purged/retained in order to ensure continuity as per requirement. Prof. Sivasami in this context mentioned the three Gorges project in China which is expected to bring more water to Yellow river. The Chairman requested to include the rivers like Yangtsi, Yellow, Elbe, etc. It was decided in the committee that the problem should be approached in a holistic manner. Prof. Sivasami contended that flood cannot be completely avoided. It was also decided that IWAI will send one official to attend the next core group meeting.

7.0 EROSION OF GANGA IN WEST BENGAL

The Secretary, irrigation and drainage, Government of West Bengal informed the committee that during the last 25 years, about 200 sq. kms of land has been eaten away by river Ganga. During 2001, Nov./Dec. Farakka Barrage authorities had referred a specific problem to CWPRS for study. CWPRS in its report did not recommend dredging, however. The Secretary added that during 2002, there was no erosion. The Chairman, Dr. B.K. Mittal referred in this context the report by Keskar Committee and reiterated that dredging is not a permanent solution.

7.01 Shri A.K.Chakraborty intervening in the discussion desired that the Damodar river should be included while giving specific recommendations.

8.0 ENVIRONMENTAL ASPECTS

Dr. K.K.S. Bhatia suggested for environmental considerations while submitting recommendations to the Government. The Secretary, West Bengal informed the Committee that stretch of Tilo nallah of 5 km was dredged and the material was disposed somewhere else to clear the choking of the nallah.

9.0 OTHER MATTERS

Shri A.K. Chakraborty, in the mean time, informed the committee that he would be out of the country from November, 2002 onwards following which Dr. B.K. Mittal requested him to nominate one official from NRSA to work in his place. He agreed to nominate one person. Shri A.K. Chakraborty suggested for selective dredging considering technical as well as economic feasibility besides environmental effects of the operation.

9.01 The Chairman agreed that morphological aspect ought to be considered while recommending anything to the Government. The Chairman enquired about Prof. Bharat Singh, Prof. K.G. Rangaraju and Prof. Garde for their contribution. Dr K.K.S. Bhatia, informed the committee that views of Prof. K.G.Rangaraju would be incorporated in the report.

9.02 The 3rd term of reference regarding desilting was discussed. It was felt that desilting encompasses several methods, one of which may be dredging. The 4th term of reference obviously stems from the former. These may be dealt in conjunction and it should be ensured that these references are taken care of while finalizing the draft report.

9.03 It was realized that case to case study before recommending any action was necessary. Shri A.K Chakraborty in this context mentioned Srisailam project where dredging was found to be very much economical.

9.04 The Committee decided albeit provisionally to hold the next meeting on the 8th Nov., 2002.

10.0 In the 5th meeting several new vulnerable reaches such as in Brahmaputra, rivers in West Bengal, etc. were pointed out by members. General Manager, Brahmaputra Board and Secretary, Flood and Drainage, Govt. of West Bengal, mentioned specific reaches/spots in Assam and West Bengal respectively. Members have submitted fresh reports/materials which are to be collated in order to cull from them relevant informations/data to be included in the report.

In view of the above fact, it was felt by the Committee that it should have more time to accomplish the assigned task. The Committee, therefore, decided to approach the MOWR through Member Secretary for extending the tenure of the Committee up to 31.12.2002. The Chairman Dr. B.K.Mittal asked the Member Secretary to do the needful in this regard.

The meeting ended with the vote of thanks.

LIST OF PARTICIPANTS WHO ATTENDED THE 5TH MEETING OF THE COMMITTEE HELD ON 04.10.2002

1.	Dr. B.K.Mittal, Ex Chairman, CWC	Chairman
2.	Shri M.Gopalakrishnan, Member (RM), CWC	Member
3.	Shri P.S. Maiti, Secretary, Irrigation & Waterways Govt. of West Bengal	Member
4.	Shri R.M.Nair, Hydrographic Chief, IWAI	Member
5.	Shri Suresh Chopra, Director, GSI	Member
6.	Prof. K.K.S. Bhatia, Scientist 'F', NIH	Member
7.	Prof. K.S. Sivasami, JNU	Member
8.	Shri A.K. Chakraborty, Group Director (WR), NRSA	Member
9.	Shri B.C.Nayak, former Engineer-in-Chief, Irrigation Deptt., Govt. of Orissa	Member
10.	Shri M.S. Shitole, Jt. Director, CWPRS, Pune	Member
11.	Shri Barkataki, General Manager, Brahmaputra Board	Member
12.	Shri S.K.Sengupta, Chief Engineer (P&D), CWC	Member Secretary
13.	Shri Gorakh Thakur, Director (Morphology), CWC	Special Invitee

No. 3/25/2001-Morpho/945-61
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 5.11.2002

Sub:- Sixth Meeting of the Committee to study the Problem of Silting in Indian rivers.

Ref:- MOWR's letter No. 2/11/2000-ER/4285-4311 dated 8.10.2001

The Sixth meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 28.11.2002 at 11.00 hrs. in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. All the members are requested to kindly make it convenient to attend the meeting.

The agenda of the meeting is noted below :-

1. To confirm the minutes of the 5th meeting held on 04.10.2002.
2. To finalise the draft report of the Committee.
3. To prepare the Ninth chapter containing recommendations/suggestions.
4. Any other item with the permission of the Chair.

Confirmation retgarding participation in the said meeting may kindly be intimated.

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

MINUTES OF THE SIXTH MEETING OF THE COMMITTEE TO STUDY THE PROBLEM OF SILTING IN INDIAN RIVER HELD ON 28TH NOV., 2002 IN THE COMMITTEE ROOM OF THE MEMBER(RM), CWC, Sewa Bhawan, R.K. Puram, New Delhi - 110066

1.0 WELCOME ADDRESS BY CHAIRMAN

The Chairman of the Committee Dr. B.K.Mittal welcomed the members for the 6th meeting. He thereafter welcomed the Secretary, Irrigation & Waterways, Government of Assam who attended the meeting for the first time. He subsequently requested the Member Secretary to start the proceeding.

2.0 CONFIRMATION OF MINUTES OF THE 5TH MEETING

The Member Secretary requested the members to confirm the minutes of the 5th meeting as no comments in this regard were received. The members confirmed the minutes of the 5th meeting.

3.0 CHAPTER - IX

The Member Secretary placed the draft IXth Chapter before members for discussions. The Member(RM) asked the Member Secretary to give complete references pertaining to the study on magnitude and frequency of flood in India for the last 40 years (1953 to 1993).

3.01 Desilting of river bed for flood control

The members discussed the topic "Desilting of River Bed for flood control". Various views were expressed citing the specific problems. The Member (RM) cited the Damodar river whose flood carrying capacity has undergone drastic changes. He further added that desilting may be helpful for obviating flood in a river. Shri S.K. Sinha, Member, GFCC suggested for dredging operation at the mouth of the river. It was the opinion of members that dredging requires space for dumping the dredged material. The Chairman, however, mentioned that reduced capacity of river in DVC system may be attributed to encroachment of the flood plains. Shri Suresh Chopra from GSI was in favour of some live example to be cited in this regard.

3.02 Efficacy of Dredging vis-a-vis Flood Control

Secretary, Irrigation & Waterways, Government of Assam mentioned the dredging operation which was carried out in Brahmaputra in 1974. The operation was called off as it did not have positive impact on the river morphology. Shri R.M. Nair from IWAI opined that local dredging may be helpful for flood control.

The Chairman finally stated that dredging may be done depending upon local conditions in order to improve hydraulic conditions of the channel. Shri S.K. Sinha, Member, GFCC in this regard cited about the morphological study on Ganga which was carried out by CWPRS, Pune. The Chairman informed the Committee that Ganga generally changes its course in every 74 years and added that Ganga, Brahmaputra, Yamuna are very mighty rivers and before undertaking the dredging of these detailed studies be carried out.

3.03 Embankment vis-à-vis Flood Control

The Member (RM) mentioned about extreme flood events which are affected by aggradation in a river bed. The Chairman informed the Committee that embankment is designed for a return period of 25 years and anti erosion schemes pertaining to town protections are formulated for a return period of 50/100 years. He further added that as per existing policy, agricultural land is not given protection against erosion/flooding in view of huge entailed expenditure on such works. Silting/desilting in the context of flood management was discussed. Prof. Sivasami stated that the committee did not address the efficacy of river dykes as it was not under the purview of committee. However, he suggested that the committee may recommend no more dykes in future. The Chairman requested the members to send their views in writing to the Member Secretary latest by 15th Nov., 2002. The Chairman desired the following statement to be included in the IXth Chapter.

"Though there are heavy sediment loads in the rivers, natural process of the self scouring of the rivers ensures that there is no substantial aggradation, if viewed in totality"

4.0 CHAPTER – X

The Chairman desired that one more chapter i.e. Chapter-X consisting of Bibliography should be included in the main report.

5.0 EXECUTIVE SUMMARY

The Chairman desired an Executive Summary which will include the gist of the whole report. As per the discussion, the IXth Chapter will be fully included in the Executive Summary.

The meeting ended with the vote of thanks.

LIST OF PARTICIPANTS WHO ATTENDED THE 6TH MEETING OF THE COMMITTEE HELD ON 28.11.2002

1.	Dr. B.K.Mittal, Ex Chairman, CWC	Chairman
2.	Shri M.Gopalakrishnan, Member (RM), CWC	Member
3.	Sh.S.K.Sinha, Member, GFCC, Patna	Member
4.	Sh. K.D.Saharia, Chairman, Brahmaputra Board	Member
5.	Sh. N.N.Goswami, Secretary, FC, Govt. of Assam	Member
6.	Dr. K.K.S. Bhatia, Scientist'F', NIH, Roorkee	Member
7.	Prof. K.S. Sivasami, JNU	Member
8.	Shri R.M.Nair, Hydrographic Chief, IWAI	Member
9	Shri Suresh Chopra, Director, GSI	Member
10	Shri M.S. Shitole, Jt. Director, CWPRS, Pune	Member
11.	Shri Y.P.Sharda, GSI, New Delhi	Member
11.	Shri S.K.Sengupta, Chief Engineer (P&D), CWC	Member Secretary
12.	Shri Gorakh Thakur, Director (Morphology), CWC	Special Invitee

No. 3/25/2001-Morpho/1101-17
Government of India
Central Water Commission
(Morphology Directorate)

839(N), Sewa Bhawan,
R.K.Puram, New Delhi – 110066

Dated : 17.12.2002

Sub:- 7th Meeting of the Committee to study the Problem of Silting in Indian rivers.

Ref:- MOWR's letter No. 2/11/2000-ER/4285-4311 dated 8.10.2001

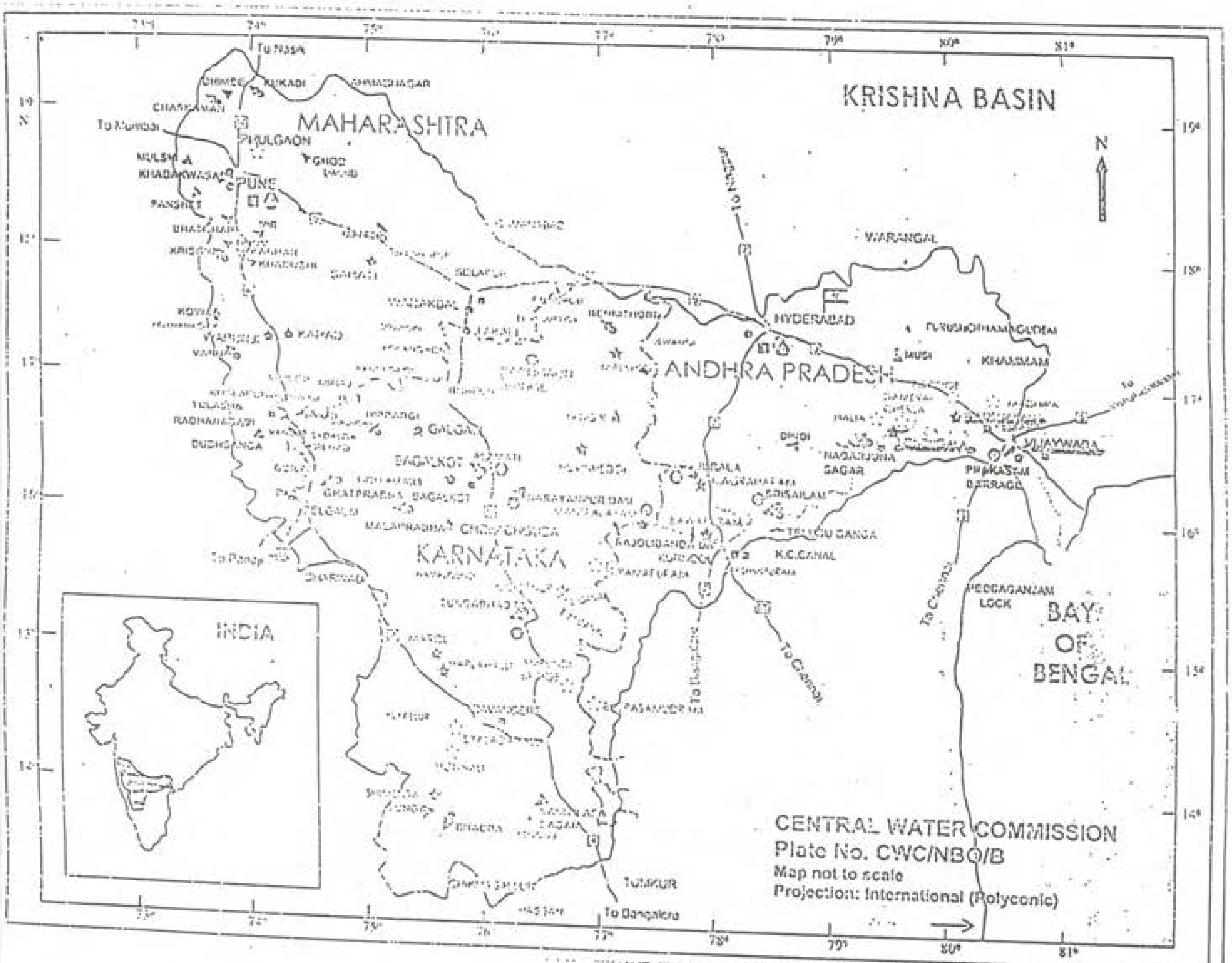
The 7th meeting of the Committee to study the Problem of Silting in Indian rivers is proposed to be held on 27.12.2002 at 03.30 PM in the Committee Room of Member (RM), Central Water Commission, Room No. 212(S), Sewa Bhawan, R.K.Puram, New Delhi-110066. This is the last meeting of the Committee in which the IXth chapter, after finalization will be approved.

The agenda of the meeting is noted below :-

1. To confirm the minutes of the 6th meeting held on 04.10.2002.
2. To finalise the report of the Committee.
3. Any other item with the permission of the Chair.

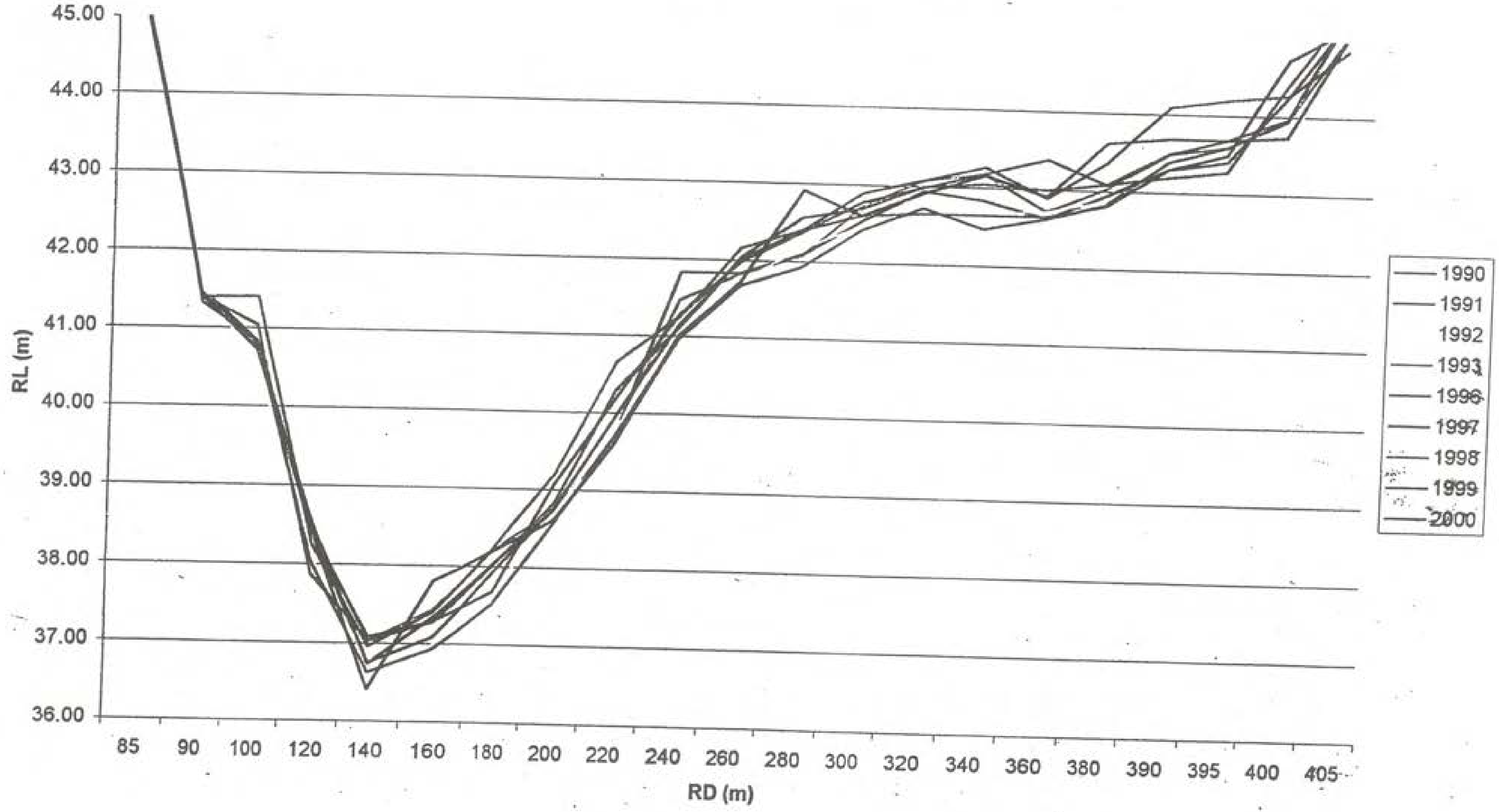
Members are specifically requested to kindly make it convenient to attend the meeting as this is the last meeting in which the report of the Committee will be approved and signed by individual members for onward transmission to the Ministry of Water Resources, New Delhi.

(S.K.Sengupta)
Chief Engineer(P&D) &
Member Secretary
Telefax - 6102267

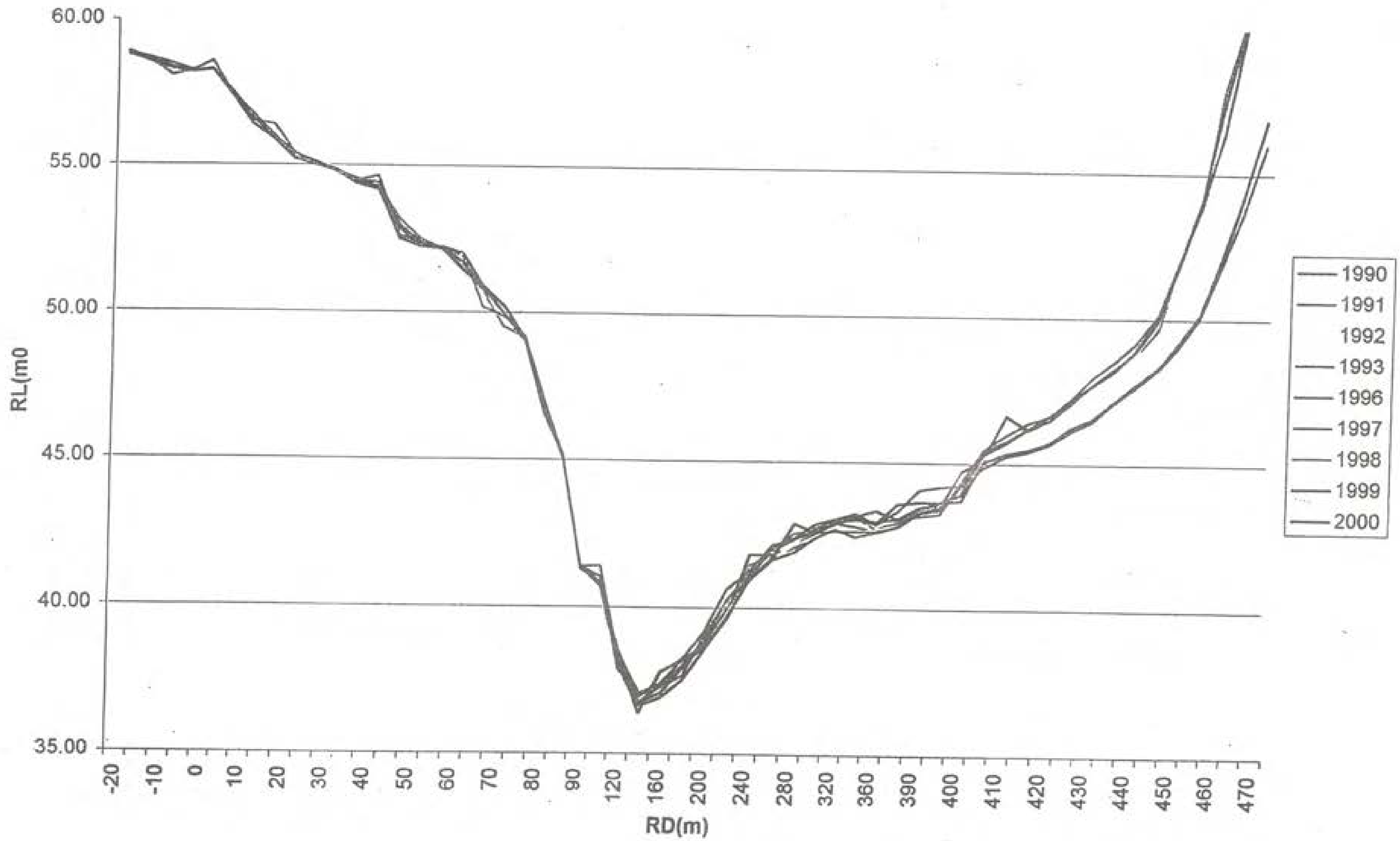


For International / State boundaries and Coast lines refer to Survey of India maps

PONDUGALA_X_SECTIONS (NEAR BED)



X_SECTIONS-PONDUGALA(1990_2000)POSTMONSOON



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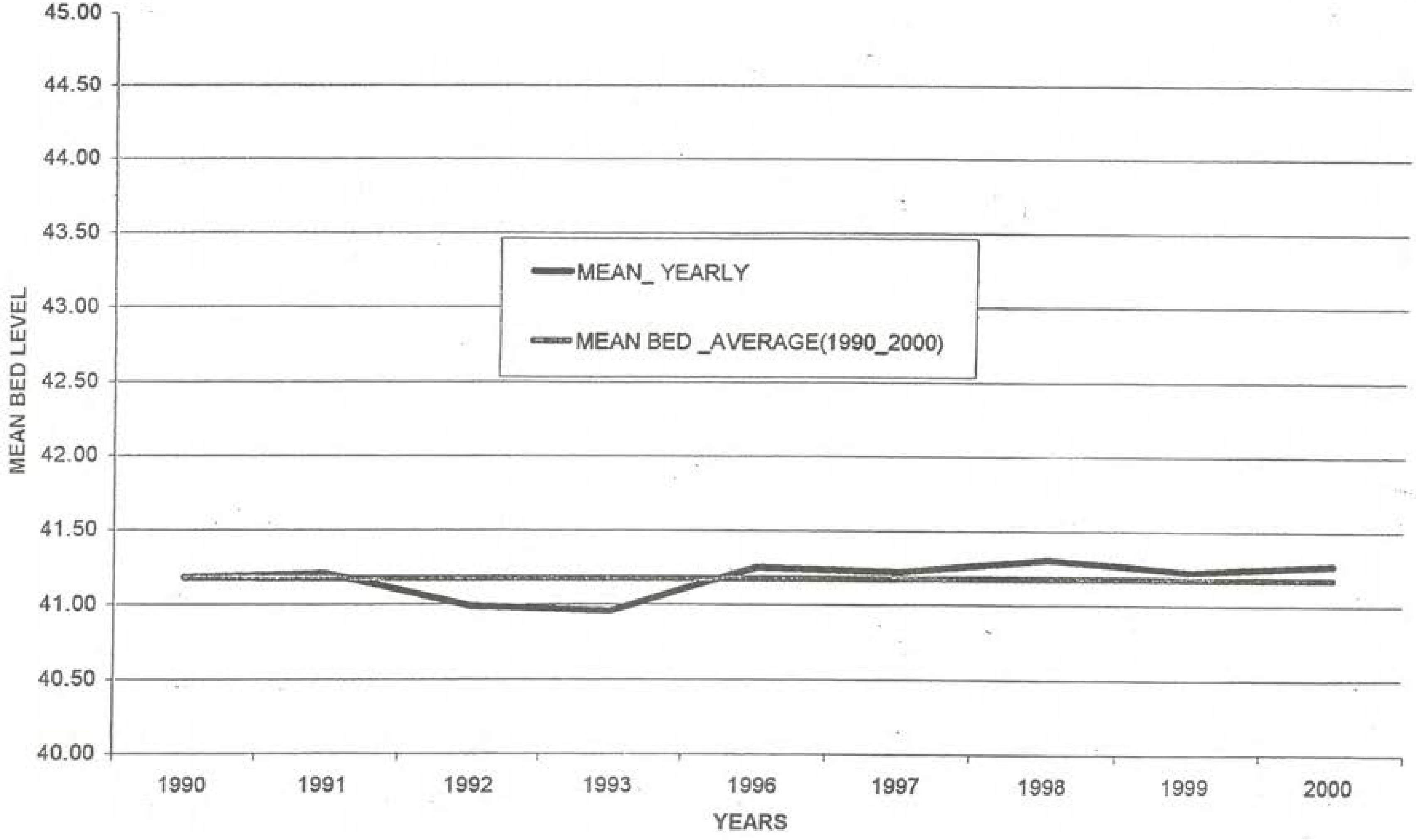
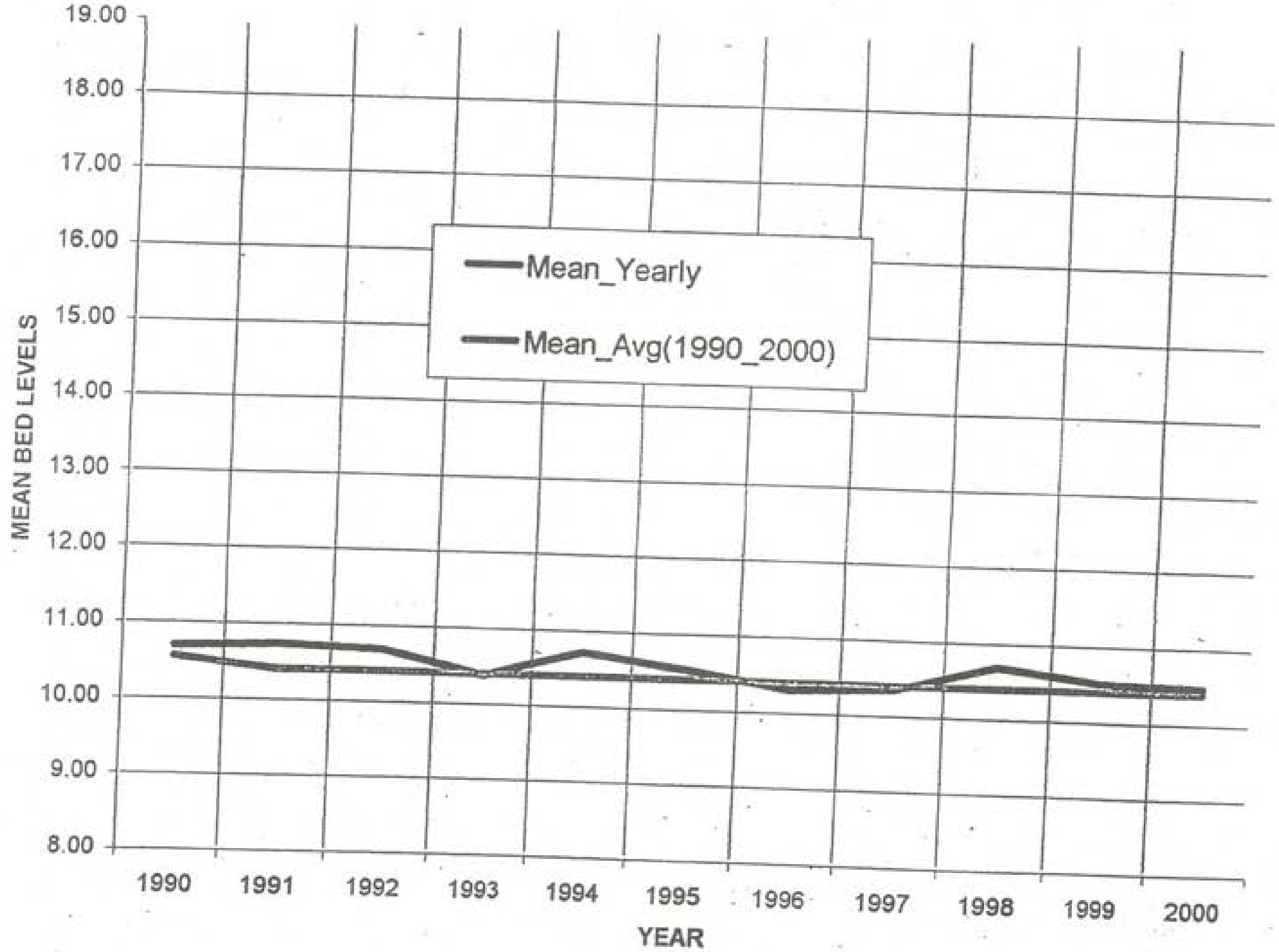
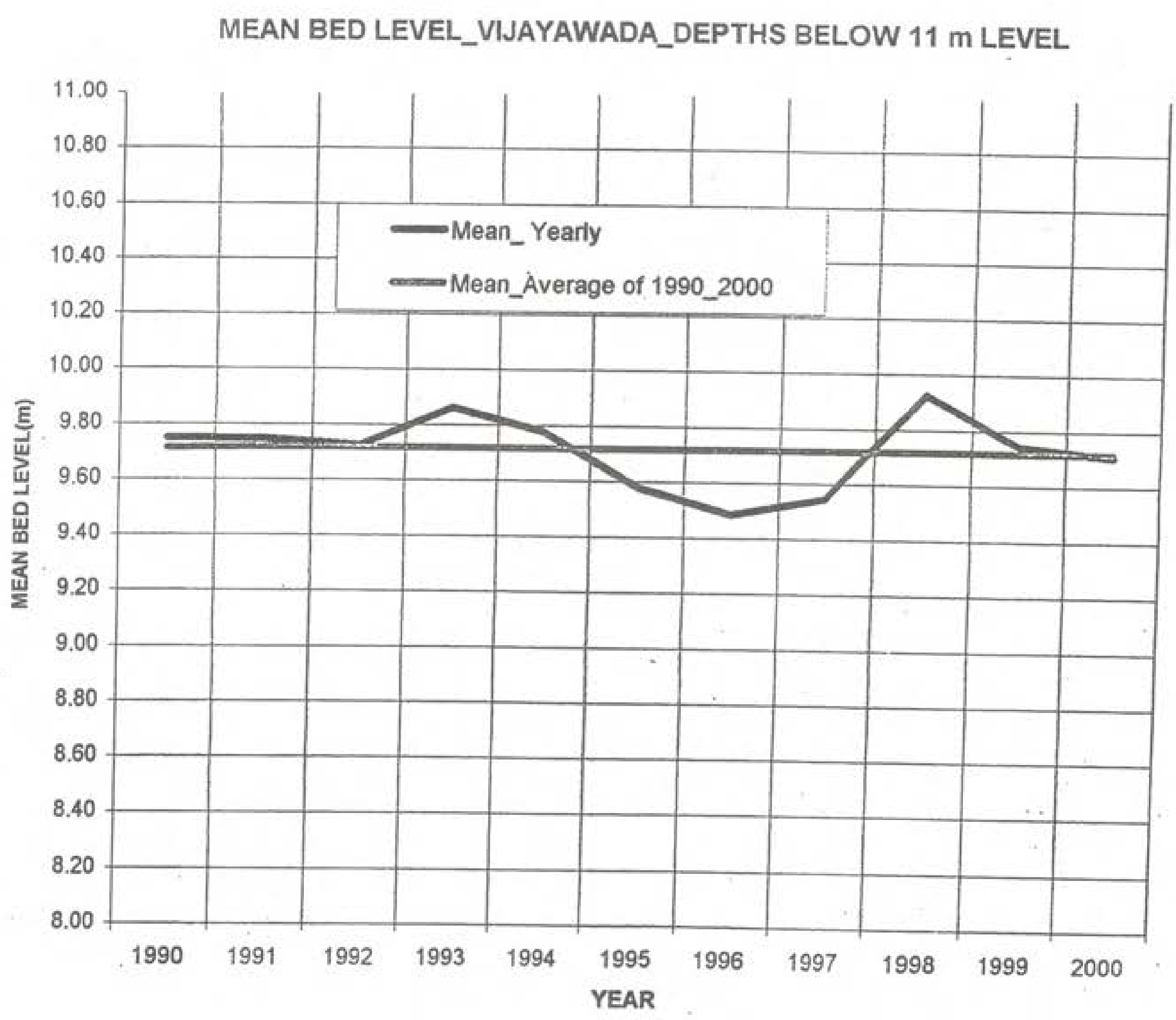
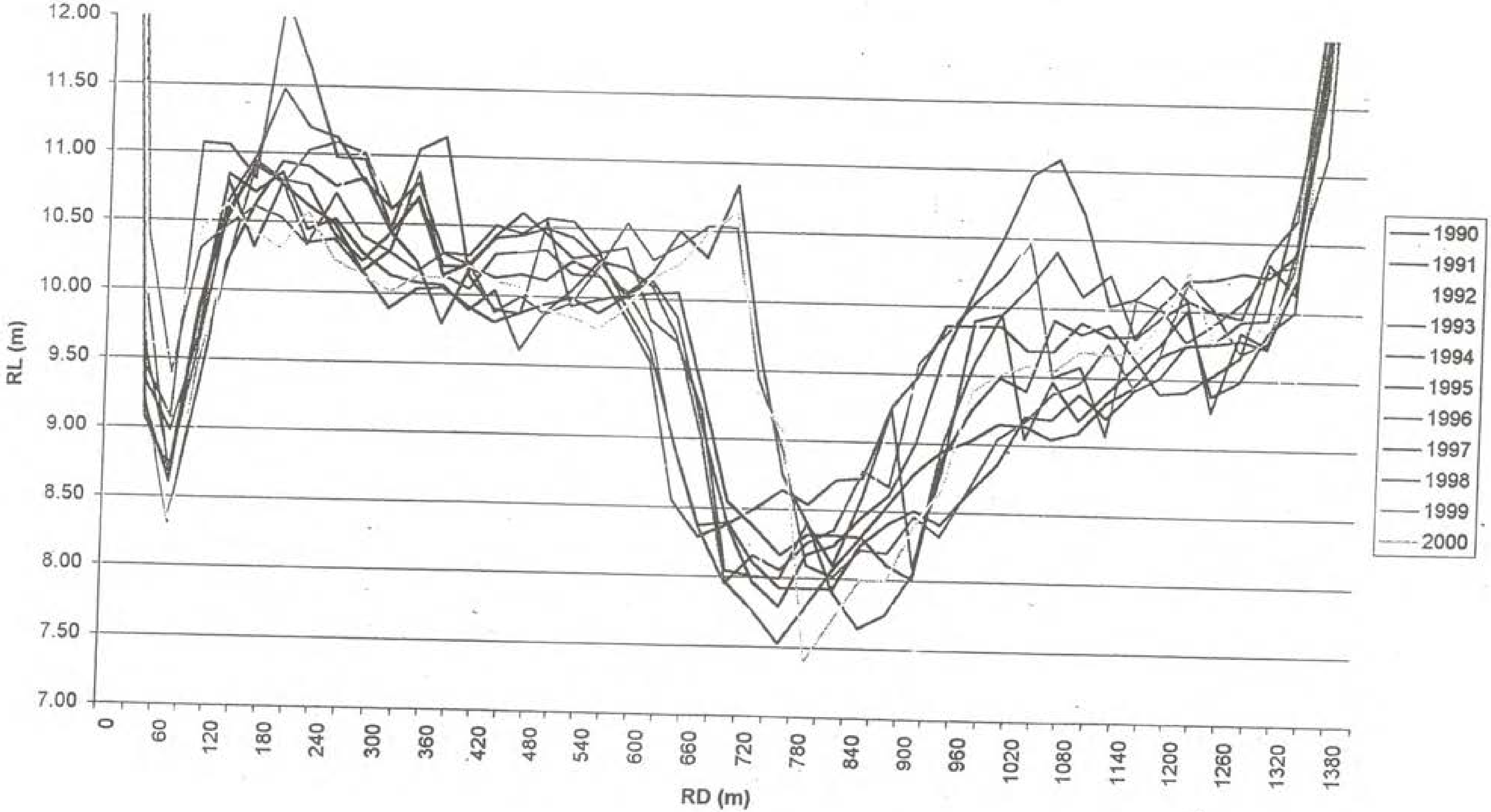


MEAN BED LEVELS_VIJAYAWADA_CONSIDERING DEPTHS BELOW 19 m LEVEL

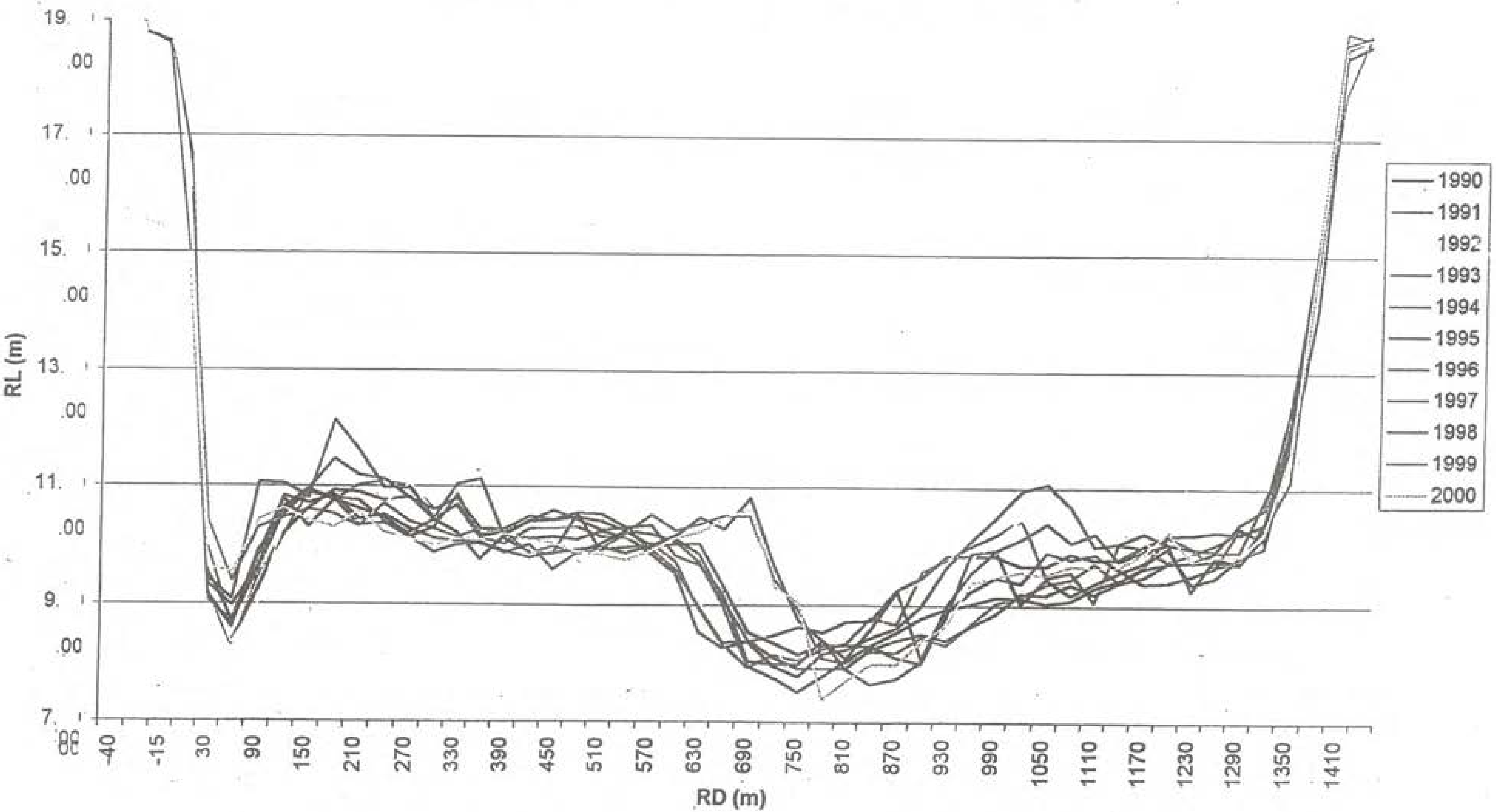



MEAN BED LEVEL_VIJAYAWADA_DEPTHS BELOW 11 m LEVEL
Mean_ Yearly
Mean_Àverage of 1990_2000
MEAN BED LEVEL(m)
11.00
10.80
10.60
10.40
10.20
10.00
9.80
9.60
9.40
9.20
9.00
8.80
8.60
8.40
8.20
8.00
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
YEAR

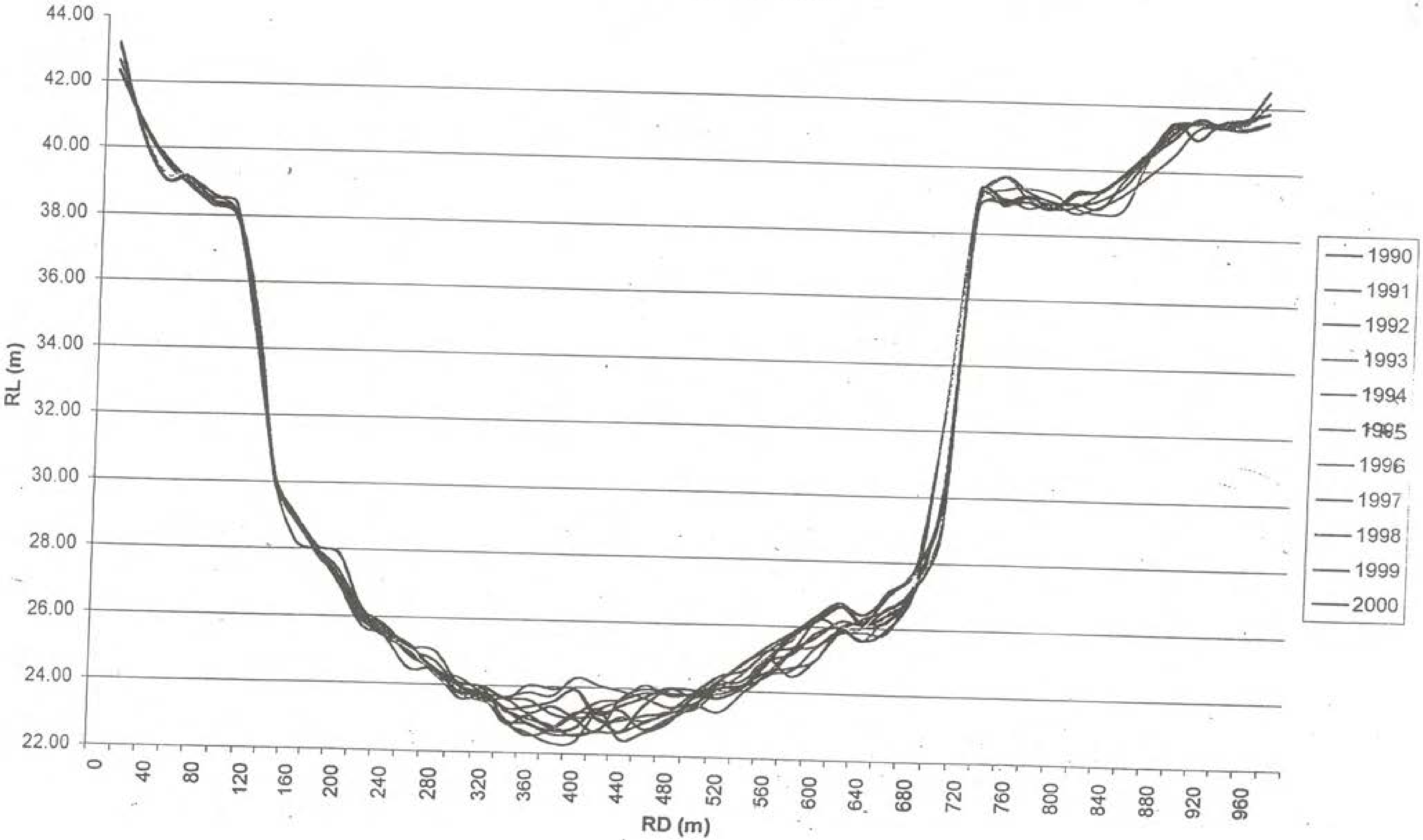
X_SECTIONS_VIJAYAWADA (1990_2000) POST MONSOON NEAR BED



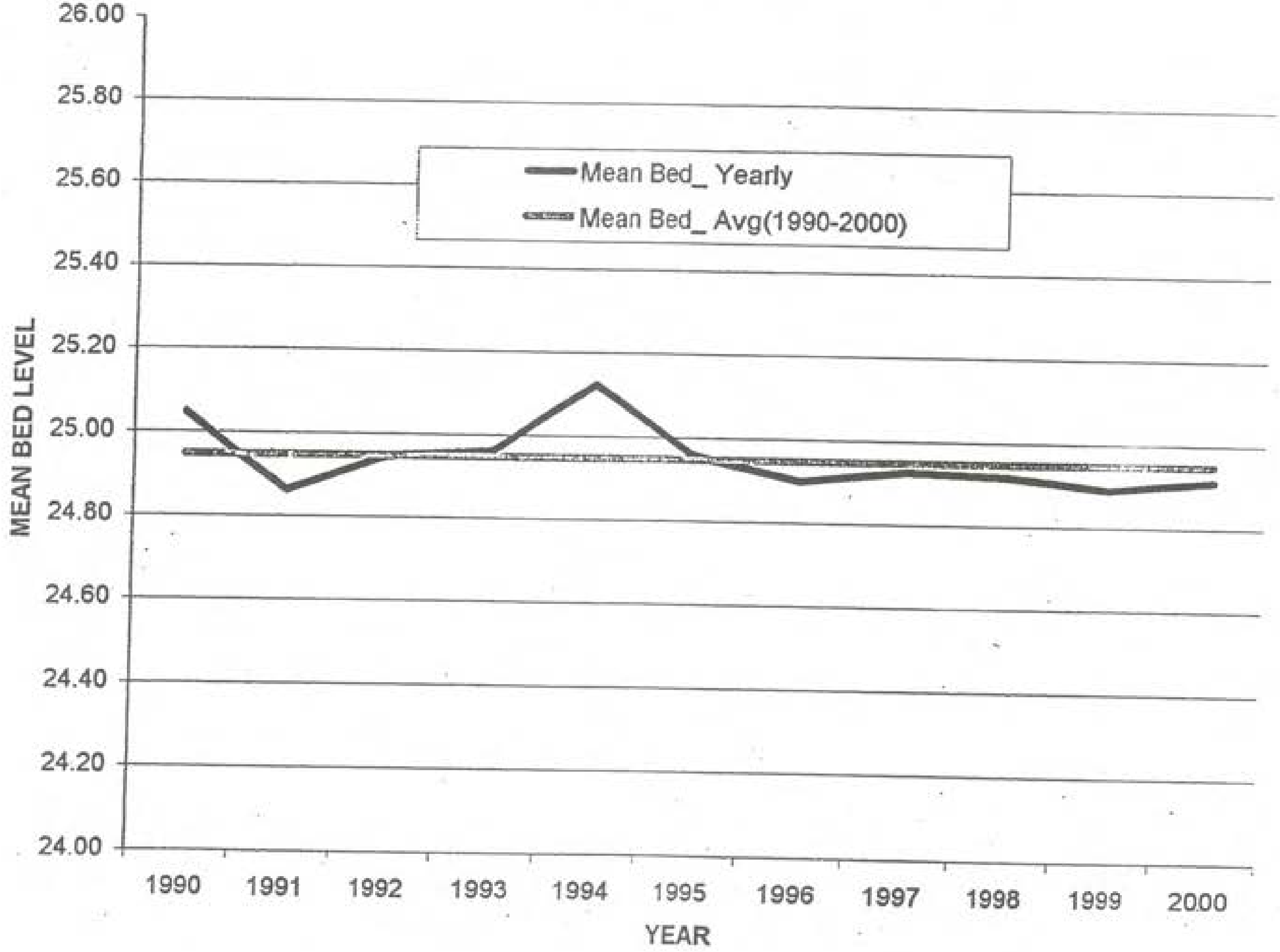
X-SECTIONS_VIJAYAWADA (1990_2000) POST MONSOON



WADENAPALLY SUPERIMPOSED X_SECTION (POST MONSOON)
FOR PERIOD 1990-2000



MEAN BED LEVEL OF KRISHNA AT WADENAPALLY (1990_2000) WITH DEPTHS BELOW 30 m LEVEL



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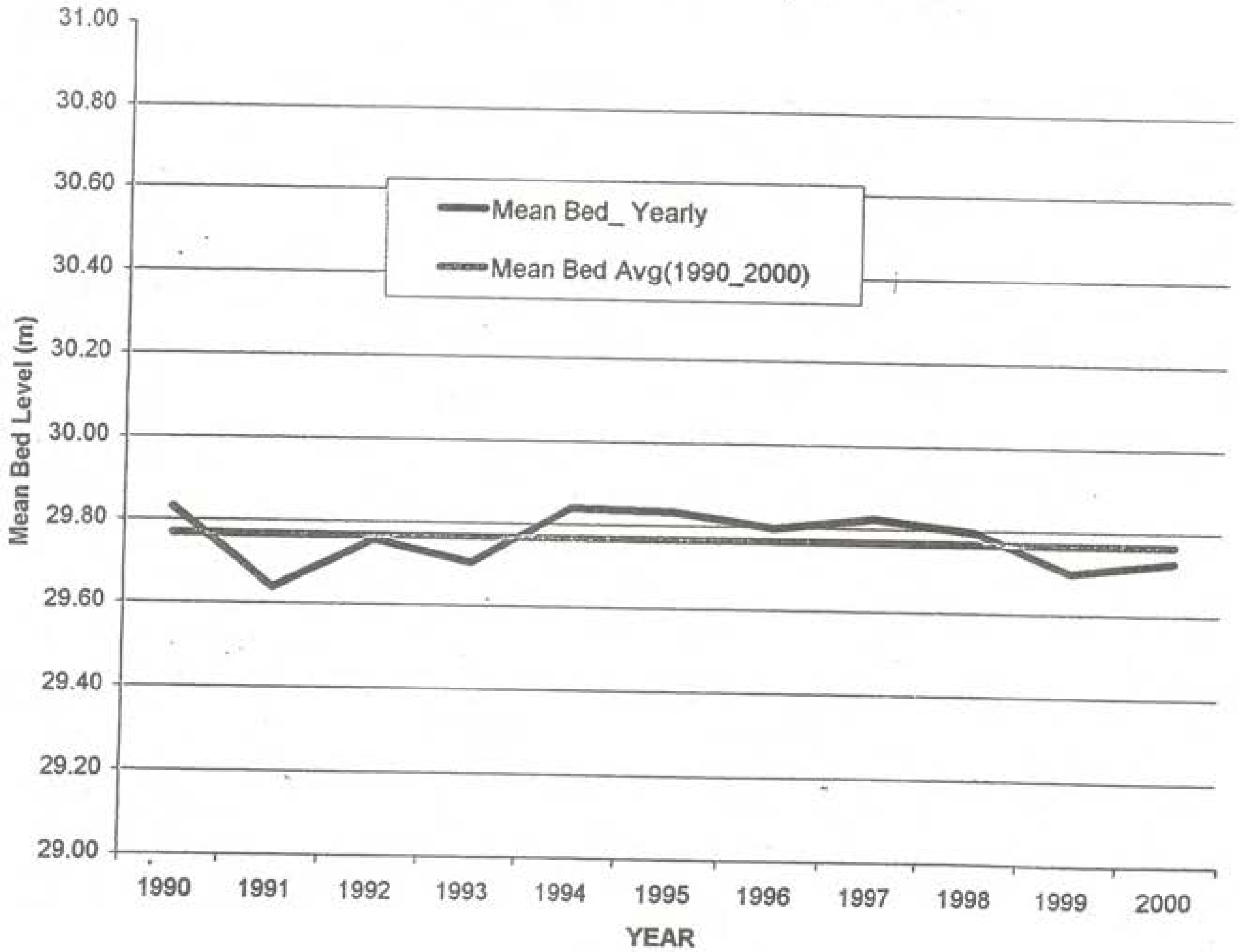
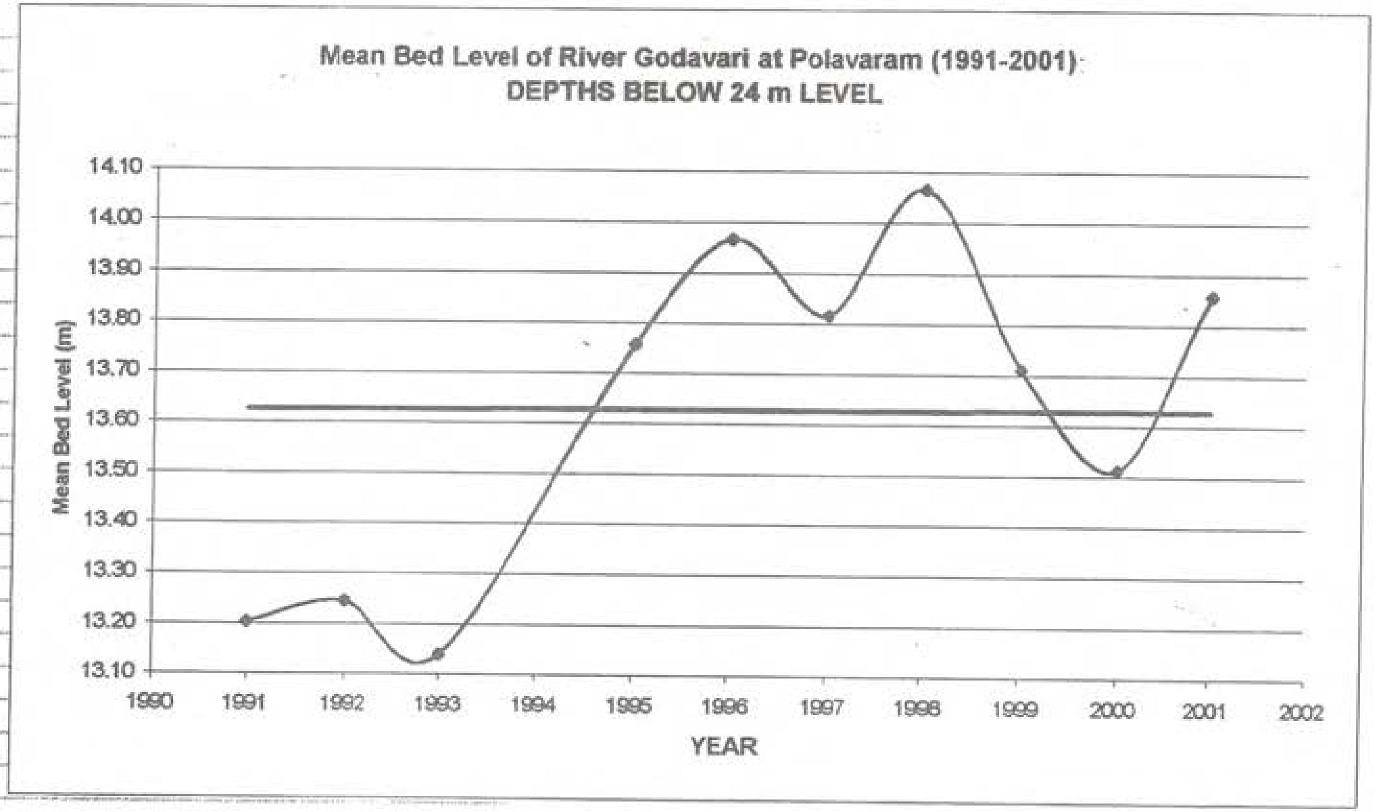
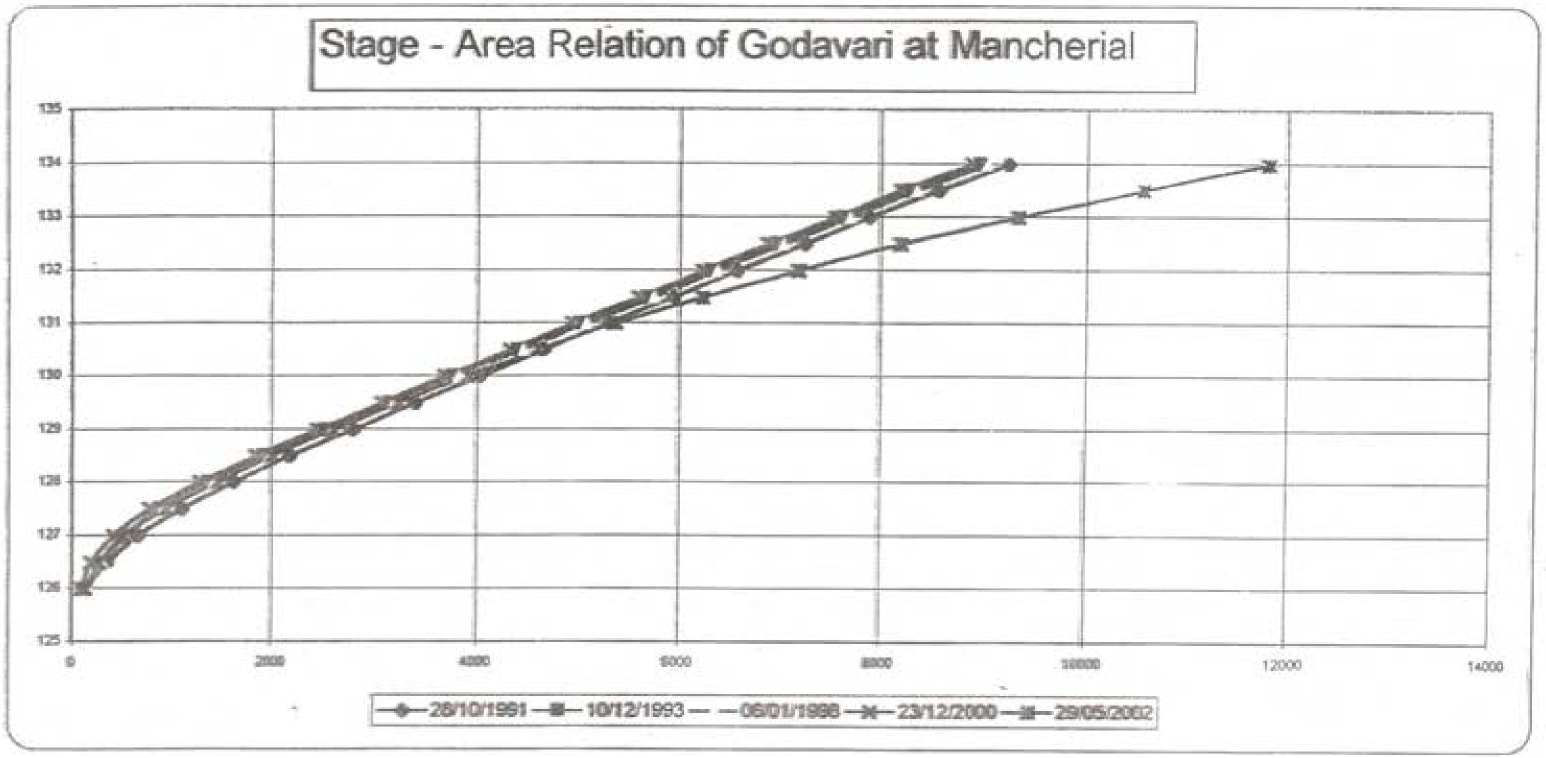


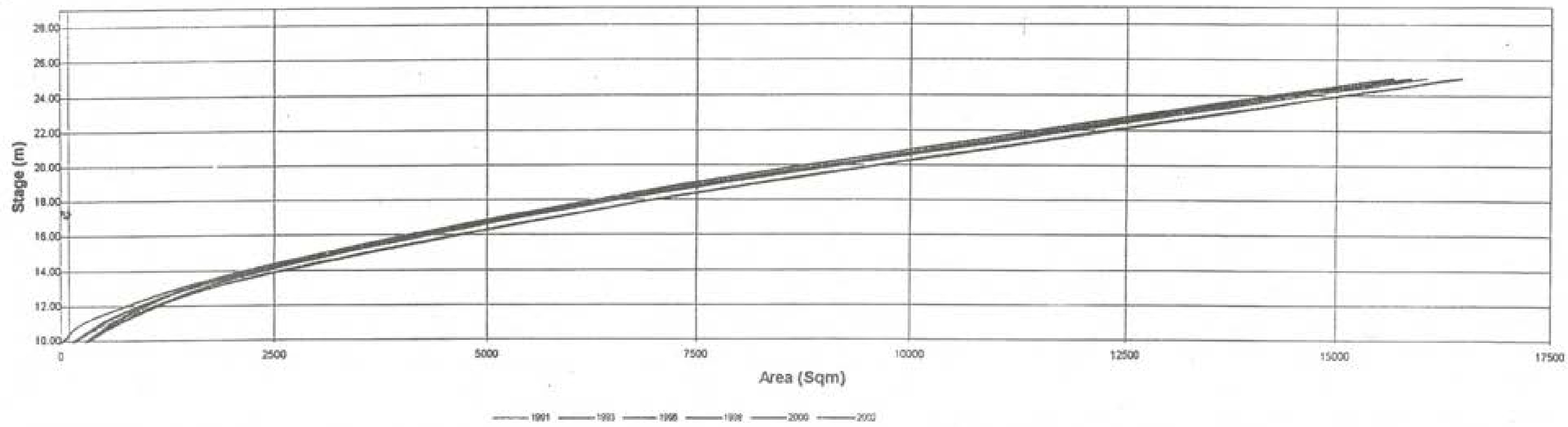
ODAVARI BASIN
NTRAL WATER COMMISSION

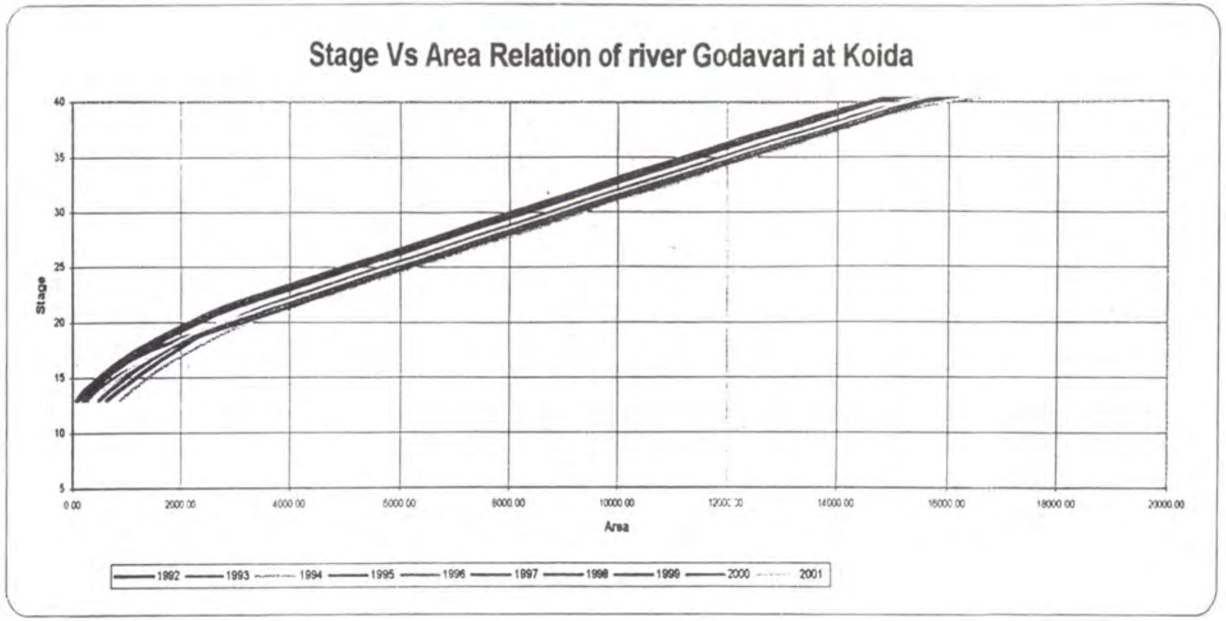
	Polavaram
1991	13.20
1992	13.25
1993	13.14
1995	13.76
1996	13.97
1997	13.82
1998	14.07
1999	13.71
2000	13.51
2001	13.86




Stage - Area Relation of Godavari at Mancherial
135
134
133
132
131
130
129
128
127
126
125
0
2000
4000
6000
8000
10000
12000
14000
28/10/1991
10/12/1993
06/01/1998
23/12/2000
29/05/2002

Stage Vs Area Relation of river Godavari at Polavaram




Stage Vs Area Relation of river Godavari at Koida
Stage
40
35
30
25
20
15
10
5
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
14000.00
16000.00
18000.00
20000.00
Area
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001